UNIVERSITY OF CALIFORNIA Mexico Initiative

The link between clean air policy and climate change policy in Mexico: Building an agenda for evaluation and research

White Paper for the Environmental Working Group of the UC-Mexico Initiative

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Paulina Oliva[1], Danae Hernández Cortéz[2], Marco Antonio Heredia Fragoso[3], Víctor Hugo Páramo Figueroa[3], Teresita Romero Torres[3], José Abraham Ortínez Àlvarez[3], Giovanna Mantagner[3], Karla Joana López Nava[3]

1. University of California, Riverside
2. University of California, Santa Barbara
3. National Institute of Ecology and Climate Change, Mexico

1111 FRANKLIN STREET, OAKLAND, CA 94607-5200; 900 UNIVERSITY AVE, RIVERSIDE, CA 92521
TEL: 951.827.4558; EMAIL: UC-MEXICO@UCR.EDU; WEBPAGE: UCMEXICOINITIATIVE@UCR.EDU

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I. Introduction

Mexico has put ambitious commitments forward in the context of the Paris Climate Agreement, a keystone in climate governance under the United Nations Framework Convention on Climate Change. Notwithstanding, the recent air pollution crisis in Mexico City during April 2016, where pollutants peaked in the greater metropolitan area of Mexico City, triggered environmental contingency plans that included restriction of industrial activities and limited the use of private cars, among other governmental actions determinations. The environmental turmoil provoked by these sudden pollution peaks in one of the largest cities in the planet calls for greater efforts to better understand and integrate climate and clean air policies. Evaluation can play a key role by shedding light on existing linkages between these policy areas, and by identifying opportunities for increased synergies.

Mexico's Climate Change Law, issued in 2012, mandates systematic and periodic evaluation of national climate policy vis-à-vis a wide range of adaptation and mitigation objectives. The climate law acknowledges a linkage between air quality and climate change mitigation by including the following evaluation objectives:

- Ensuring the health and the security of the population through air pollution control and its reduction;

- Reducing emissions of greenhouse gases and compounds in the transport sector; and

- Increasing energy efficiency of vehicles through standards and emissions control.

National Climate policy evaluation is carried out by the Evaluation Coordination, a group comprised by six social advisors and the General Director of the National Institute of Ecology and Climate Change (Instituto Nacional de Ecología y Cambio Climático or INECC), with the support of INECC's General Coordination for Evaluation of Mitigation and Adaptation Policies, which serves as its Technical Secretariat.

As the Evaluation Coordination is starting its first evaluation cycle, INECC and the University of California have embarked in a collaboration geared at exploring evaluation and research opportunities on the several linkages between clean air and climate change policies. This collaboration is part of ongoing efforts, led by the Working Group on Environment of the UC-Mexico Initiative, which are aimed at establishing a shared perspective on, and a common approach to climate change in Mexico and California by fostering joint research and education projects.

Within this framework, the objective of this white paper is to propose an evaluation and research agenda that builds upon the notion that clean-air policy implementation supports advancement of climate change policy. As part of this objective, we identify the methodological challenges to be addressed by researchers, policy makers and evaluators in order to conduct rigorous evaluation.

The first section of this document provides a background on clean air and climate change policies in Mexico. The second section provides a general framework for thinking about co-benefits, identifies the sources of these, and discusses some of the existing empirical evidence on their importance. The third section uses the theory of change approach to identify relevant clean air interventions with opportunities to contribute to climate change mitigation. The fourth section discusses methodological challenges for the evaluation of the climate change benefits of clean air interventions and outlines ways to address them. The last section discusses conditions that would facilitate the evaluation of clean air and climate change policies in Mexico. This section also features potential opportunities for further collaboration between the University of California and INECC with the purpose of refining and potentially implementing key areas of the proposed agenda.

II. Clean air and climate change policies in Mexico

Clean Air policy, as such, has existed in Mexico since the early 70s. The Federal Law to Prevent and Control Atmospheric Pollution (*Ley Federal de Prevención y Control de la Contaminación Atmosférica*) was issued in 1971 as a response to the increasing air quality degradation and other environmental impacts caused mainly by industrial activities and urban expansion. This legislation and derived policy implementation was under the authority of Secretariat of Health and Assistance (*Secretaría de Salubridad y Asistencia*) through the Deputy-Secretariat of Environmental Improvement (*Subsecretaría de Mejoramiento del Ambiente*). In the early 80s, the Federal Law for Environmental Protection was issued seeking to broaden the scope of environmental governance and protection. In the late 80s, the General Law for Environmental Protection and Ecological Equilibrium (*Ley General del Equilibrio Ecológico y la Protección al Ambiente or LGEEPA*) was issued seeking to outline the authority of federal Secretariat of Urban Development and Ecology – (*Secretaría de Desarrollo Urbano y Ecología - SEDUE*), and corresponding state and municipal authorities for environmental protection, and also, it aimed at incorporating social and private participation for environmental protection. The Secretariat of the Environment, Natural Resources and Fisheries was created in 1994, and it was mainly responsible for environmental and natural resources policy design, implementation, and management.

With major reforms in 1996, LGEEPA establishes principles and policy instruments for environmental and natural resources protection. In the air quality realm, under the authority of LGEEPA, federal authorities are responsible for issuing compulsory standards (known as *Normas Oficiales Mexicanas or NOMs*) and voluntary standards (also known as *Normas Mexicanas or NMX*), designing and enforcing environmental provisions, managing the pollutant releases and transfers registry (otherwise known as *RETC – Registro de Emisiones y Transferencia de Contaminantes*), integrating information for air quality into the National System for Environmental Information, among others. State authorities are responsible for similar activities at the state level according to specific regulations. Municipal authorities are responsible for managing and enforcing environmental and urban bylaws at the local level.

Under the implementation of LGEEPA, federal, state and municipal authorities share three main responsibilities for environmental protection: ensuring compliance with air quality standards, monitoring air quality, and enforcing respective regulation in case of the non-attainment of existing standards. In this realm, air quality management programs (*Proaires*) provide general guidelines for the development and implementation of air quality policies in a state, region or metropolitan areas. In addition, federal and state level legislation call for the elaboration of emission inventories that keep track of mobile and point sources of criteria pollutants, such as carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), particulate matter (PM), volatile organic compounds (VOCs), and ammonia (NH_3).

The linkage between clean air and climate policy was absent from policy until very recently. It appeared first in the National Strategy on Climate Change, which was issued in 2013 and serves as planning framework for climate policy. This framework establishes targeted strategies for mitigating climate change such as the transition to clean energy sources, the creation of sustainable cities, the improvement of urban transport and mobility, and the overall reduction of short-lived climate pollutants. The link to air quality appeared more explicitly in the Special Program on Climate Change for 2014 – 2018 (*Programa Especial de Cambio Climático 2014 – 2018 or PECC*), a federal mandatory program that establishes specific objectives derived from the National Law of Climate Change. PECC points out the importance of reducing short-lived climate pollutants due to the co-benefits in health and welfare. Moreover, some of PECC's specific objectives are intended towards the use of technologies and fuels that reduce black carbon emissions, the implementation of sustainable urban transportation, and the incorporation of retrofit technology in diesel units. PECC thus stresses the importance of air quality interventions, and because of its mandatory nature for all government agencies, it provides a solid motivation for exploring and pursuing linkages between air quality and climate policies.

More recently a National Clean Air Strategy (*Estrategia Nacional de Calidad del Aire or ENCA*) was unveiled by the Federal Government. ENCA is a planning and coordination tool that seeks to align actions among different governmental actors to control, mitigate and prevent concentration of pollutants emissions in the atmosphere in urban and rural areas with projections to the year 2030. Finally, the Program for Air Quality Improvement the Greater Mexico City Metropolitan Area (*Proaire 2011 – 2020*) calls for the design of comprehensive policy solutions, provided that, one activity or facility is commonly the source of emissions contributing to different pollutants and clearly outlines the link between criteria pollutants and GHGs.

III. Climate change mitigation co-benefits of clean air policies

Environmental regulation that specifically targets criteria pollutants (such as ozone, particulate matter, nitrogen oxides, sulfur dioxide and carbon monoxide) might have consequences for the attainment of non-targeted environmental goals such as mitigation of climate change. Likewise, policies that target greenhouse gas reductions could potentially affect emissions of criteria pollutants. These cross-regulatory spillovers are known as co-benefits or ancillary benefits (whenever the consequences are positive) or ancillary costs (whenever the consequences are negative). Understanding these interactions is very important for policy design because their existence impacts cost-benefit ratios of environmental regulation and may also change the optimal stringency of environmental standards. The existence of these spillovers also implies that optimal policy design that targets green-house gases and criteria pollutants requires coordination or integration of these policies.

It is also worth noting that the scope for these spillovers across policies is large, as it is usually the case that the sources of greenhouse gases are the same as the sources of criteria pollutants. For example, combustion processes in vehicle and industrial engines generate carbon dioxide as well as particulate matter, and other pollutants depending on the type of fuel and combustion technology. Grennfelt et al. (1994) establish the connections between main emission sources, chemical compounds, effects and media receptors. Figure 1 modifies these relationships by including short lived climate pollutants.

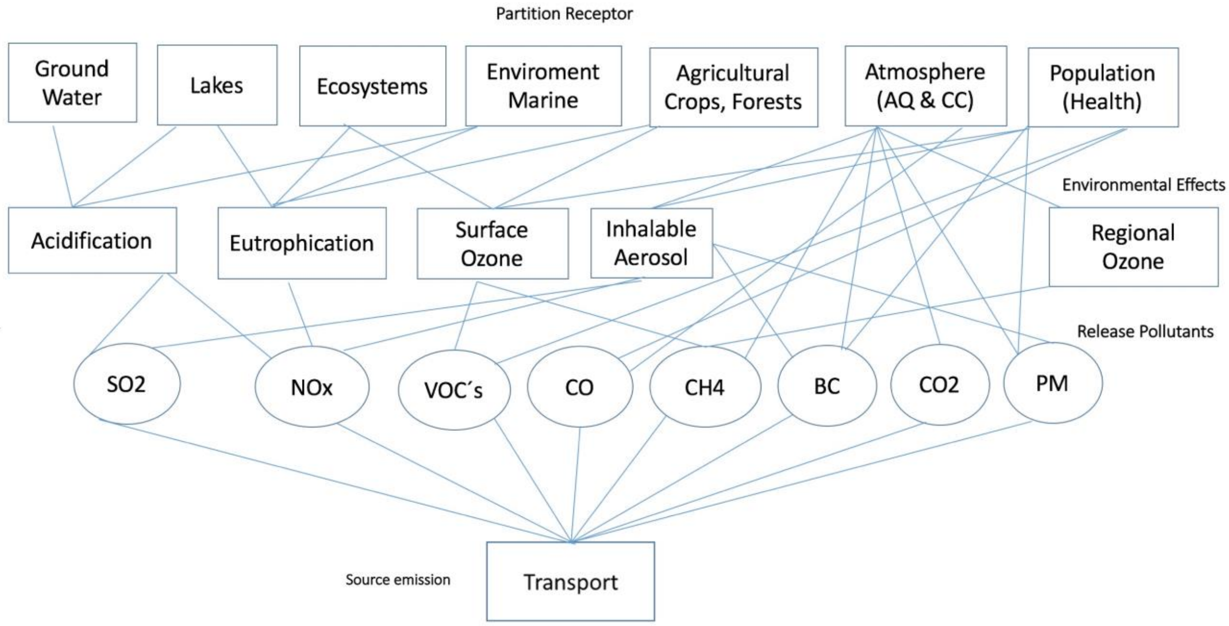

Figure 1. Relation between transport emissions, pollutants, effects and main receptors.

The bottom row of this figure shows transportation/mobile emissions sources. The second row bottom-to-top shows the primary compounds that can either directly have a negative impact on the receptors (top row) or can be transformed by intermediate processes (third row from bottom to top) that deliver harmful effects to the receptors (top row). As can be seen from this figure, transportation sources are involved in the generation of chemical compounds that contribute to climate change and have a negative effect in population health and productivity. Therefore, any policy intervention aimed at regulating transportation/mobile sources is likely to have an impact on multiple receptors and thus have ancillary benefits or costs.

Economic theory offers a useful conceptual framework that helps us characterize the general situations in which we are likely to find ancillary benefits or ancillary costs of environmental regulation given profit maximizing firm behavior. Stephen Holland, a professor in the Economics Department of the University of North Carolina at Greensboro, proposes a simple economic model that links emissions of criteria pollutants to greenhouse gas regulation and *vice versa*.[1] Conceptually, emissions of criteria pollutants and greenhouse gases can be thought of as inputs into the production processes. If criteria pollutants and greenhouse gases are complements in the firms' and households' production process, then it is likely that a regulation that mandates the reduction of criteria pollutants will also result in the reduction of greenhouse gases. The potential for complementarities and substitution in the production of these two types of emissions is very clear in the case of fossil fuel combustion. Combustion of fossil fuels results in emissions of both greenhouse gases and criteria pollutants. In the absence of regulation, firms and households are free to use as many of inputs as desired to maximize their profit. When a regulation mandates the reduction of nitrogen oxides, for example, or effectively institutes a price for nitrogen oxides emissions as in the case of the tradable permit system for nitrogen oxides in the U.S., this criteria pollutant ceases to be available for free. Firms adjust production processes to either meet the

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[1] Holland, S. (2012) Spillovers from climate policy to other pollutants. In: Fullerton, D. Wolfram, C. (Eds.) The Design and Implementation of US Climate Policy. National Bureau of Economic Research Conference Report; University of Chicago Press, Chicago, 79-90.

mandated levels or minimize costs of production in light of the new emission fee, which naturally results in the reduction of nitrogen oxide emissions. If nitrogen oxides and carbon emissions are complements in the production process (e.g. if fossil fuels that result in high carbon emissions per KWh are also more likely to emit nitrogen oxides), carbon emissions are likely to fall along with nitrogen oxides. If, however, nitrogen oxides and carbon emissions are substitutes in the production process (e.g. in the choice of diesel vs. gasoline for vehicles, as diesel is more fuel efficient but generates more nitrogen oxides than gasoline), a regulation targeted towards reducing the criteria pollutant will lead to higher greenhouse gas emissions. Thus, when emissions are substitutes in the production process, regulation that targets criteria pollutants can result in more greenhouse gas emissions or ancillary costs (as opposed to benefits).

In addition to substitution and complementarity considerations, Holland's work also highlights the importance of the output effect. Environmental regulation often leads to a reduction in the production of polluting goods. In the fossil fuel example, this would be the case of a reduction in the use and production of energy. The output effect will always lead to co-benefits, and in some cases, may be large enough to outweigh any existing substitution effects.

In practice, the substitutability or complementarity between different pollutants that Holland's work emerges from the interaction between firm behavior and the technological constraints under which firms operate, i.e. the production and abatement technologies available to them. Therefore, it is also important to understand the technological sources of pollutant interactions. There is an inherent relationship between criteria pollutants and GHG since both of them are originated from the same processes such as fossil fuel combustion, which presents opportunities to impact both types of emissions with a single policy instrument (West, et al. 2004). The scientific literature recognizes two types of policies to target air pollutants: structural changes, such as changing fuels to improve energy efficiency, and "end-of-pipe" options, like adding a flue-gas desulfurization scrubber to a coal-fired power plant (Bollen, 2015). These policies, aimed at improving air quality, will also affect CO_2 emissions.

Abatement technologies for criteria pollutant reduction in mobile sources are likely to have important effects on GHG emissions. First, structural change policies aimed at these sources, such as reducing miles traveled, are likely to reduce both criteria pollutants and GHG emissions as mobile sources are responsible for several criteria pollutants (CO, $PM_{2.5}$, PM_{10}, NOx and SO_2) and black carbon (BC) as well as GHG (photochemical smog, NOx, and CO_2) (Baklanov, Molina and Gauss 2016). As Thambiran and Diab (2011) point out, a common origin of pollution is the incomplete combustion of the gasoline in the engine emitting CO, VOCs and particulate matter (PM), which could be targeted by installing fuel-efficiency technologies which could also impact the emissions of CO_2 per mile travelled. Second, end-of-pipe technologies may be used to reduce the trade-offs between CO_2 and criteria pollutant reductions. An interesting case of this is the use of diesel engines. The diesel engine has been an attractive technology for many countries, given that it reduces CO_2 emissions and provides other benefits for reducing CO and HC. Nevertheless, PM, which include BC, and NOx emissions by diesel vehicles are very high. Without additional end-of-pipe technologies, diesel engines can be very damaging to air quality (Walsh, 2008). However, the recent cheating scandal involving Volkswagen (Gates et al. 2016) shows that these technologies are still quite expensive to be widely used as a mean to reduce the trade-off or substitutability between GHG and criteria pollutants in transportation[2].

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[2] Gates, G., Ewing, J, Russell, K & Watkins, R. (October 25, 2016). Explaining Volkswagen's Emissions Scandal., *The New York Times*. Retrieved from:

Abatement technologies that are available for power plants are likely to induce important pollutant interactions. Agee, et al. (2014) point out four of them: (1) switching to lower-sulfur, lower-Btu Western coal that produces more coal burned by kWh, which increases PM, BC, NOx, and CO_2; (2) inefficiently operated flue gas desulfurization that captures SO_2 and generates more CO_2; (3) amine-based technologies that capture CO_2 at coal-fired power plants with a co-benefit of SO_2 reductions; (4) shutting down old, dirty plants to meet SO_2 or NOx standards, reducing CO_2 simultaneously.

Energy efficiency stands out from other types of abatement technologies because in addition to its potential in reducing criteria pollutants and GHG, it reduces marginal production costs. This feature makes energy efficiency policies very appealing for policy makers. However, theoretical and empirical work in economics has highlighted that the way households and firms respond to energy efficient technologies might undermine the emission reduction benefits of such policies. As Davis, Fuchs and Gertler highlight (2014) in the case of the Mexican program aimed at incentivizing the replacement of energy-inefficient home appliances, households appear to intensify the appliance use once they replace it for a more energy efficient one, leading to just a fraction of the energy use reductions predicted by the World Bank based solely on the technical specifications of the new appliances. The observed behavior is consistent with economic theory: the relative price of the service the appliance offers (i.e. air cooling) is reduced by energy efficiency, thus inducing an increase in its demand. The case of energy efficient technologies highlights the importance of accounting both for the technical and behavioral aspects of abatement technologies when thinking about interactions between pollutants.

IV. Opportunities for evaluation

Despite the plausible mechanisms for co-benefits outlined above, there is little empirical evidence on the co-benefits of clean air policies for climate change mitigation in Mexico. Evaluation has thus a key role to play in analyzing their climate-related impacts and in identifying opportunities to strengthen synergies. In response to this, this section proposes a set of clean air interventions that should be considered as a priority for climate policy evaluation.

Climate policy evaluation is a novel policy instrument in the framework of the Mexican Climate Change System. Figure 2 shows the position of the Coordination of Evaluation in the Mexican Climate Change System.

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http://www.nytimes.com/interactive/2015/business/international/vw-diesel-emissions-scandal-explained.html?_r=0

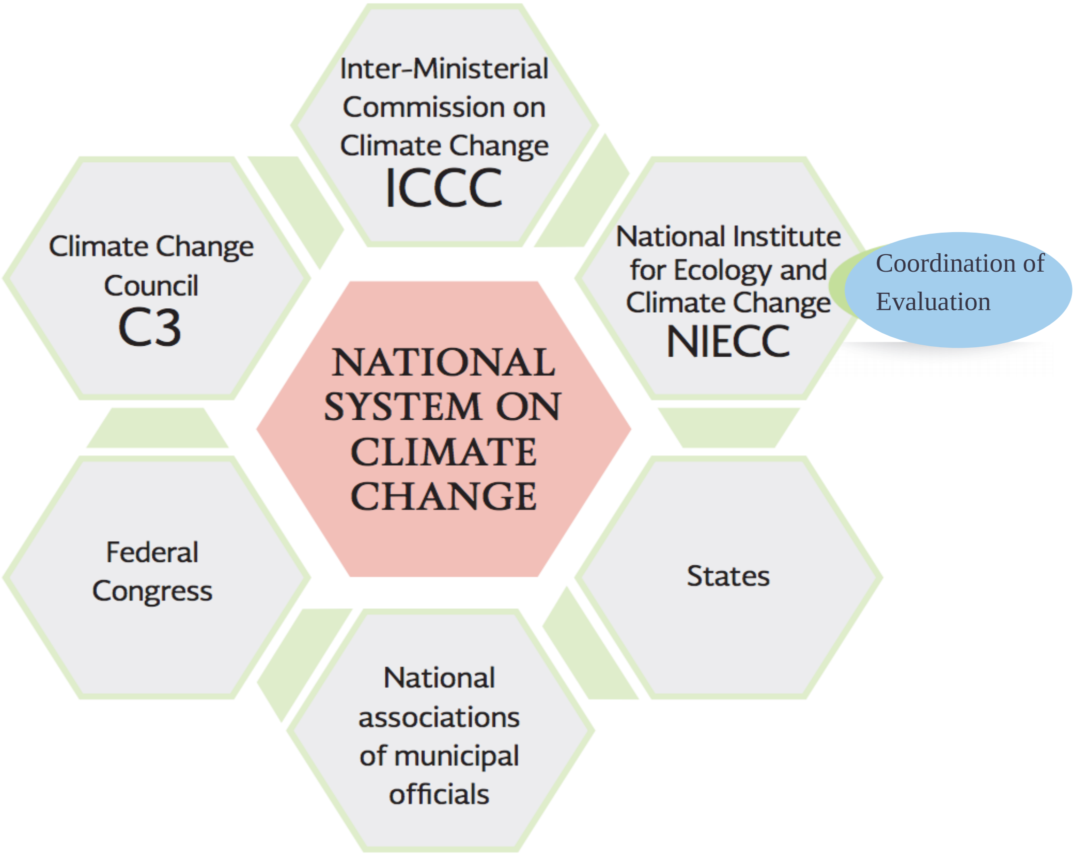

Figure 2. National Climate Change System – Source: modified from National Strategy on Climate Change.

As described in Figure 2, the National Climate Change System comprises the Interministrerial Comission on Climate Change, 14 cabinet-level representatives, the Climate Change Council, a group of at least 15 members of the public representing the academia, technical or industrial sectors. Both Chambers of the Congress are also part of the System, along with Association of Municipalities and State Authorities addressing Climate Change. The National Institute of Climate Change and the Coordination of Evaluation also have a role to play, the former, informing and providing best information available for policy implementation and the latter, providing results and recommendations to adjust and improve public climate policy.

In this vein, the Coordination of Evaluation has chosen a theory of change approach to address climate evaluation. The theory of change approach is an analytical model that helps explain how and why an intervention, a public policy, or an organization is expected to contribute to a desired end goal, by reconstructing the causal chains of intermediate results or conditions that need to take place so that the end goal can be achieved (Bours, McGinn and Pringle, 2014). In the specific case of air quality, causal linkages and conditions can be characterized by means of scientific knowledge on the chemical processes that result in GHG and criteria pollutant emissions, institutional knowledge on the regulatory framework that constraint individual and organizational behavior, economic theory that studies how individuals react to incentives given individual preferences when acting rationally, and common psychological (non-rational) responses to incentives.

This approach is particularly suited for monitoring and evaluation of environmental and climate policies and interventions, because it can contribute to identify the complex and crosscutting nature of climate change. As Mexican climate policy encompasses a myriad of interventions in different sectors and spheres of government, where quite often boundaries are unclear, the Evaluation Coordination adopted this approach to define the scope of their evaluation authority, i.e., to identify subject matter for climate policy evaluation.

However, Mexican climate policy was not designed using a theory-based approach; therefore, its theory of change was reconstructed in an ex post exercise based on a review of existing legal and planning instruments –namely, the General Climate Change Law, the National Climate Change Strategy, the Special Climate Change Program and other relevant plans- as well as workshops with stakeholders, both private and public that participated in the design and implementation of such instruments. The resulting map identifies the conditions that are implicitly assumed to be necessary to achieve climate policy objectives (see Annex I).

Based on this theory of change, a two-step analysis was implemented to identify clean air interventions that are relevant for climate change mitigation. First, a review of clean air interventions was carried out based on existing policy documents. This review included interventions under implementation in the transport, industry and energy sectors, which constitute the major GHG emitters in Mexico according to the 2013 National GHG Inventory, and are also important sources of Short-Lived Climate Pollutants (SLCPs) such as black carbon and ozone precursors. As emission sources from these sectors are concentrated in the three largest metropolitan areas in the country -Mexico City, Guadalajara and Monterrey-, the review focuses on interventions that are implemented in these cities. Some of these interventions, particularly standards, are issued by the federal government and are enforceable in the whole national territory, whereas others are implemented locally by state and municipal authorities.

Based on this review, the second step of the analysis consisted of determining the linkages between clean air policy interventions and climate change policy by identifying the contribution of these interventions to conditions in the theory of change map. A major number of clean air interventions in Mexico City, Guadalajara and Monterrey relevant for climate change mitigation are implemented in the transportation sector, which is the largest emitting sector in Mexico. These policy interventions include emissions controls, driving restrictions, increasing the efficiency and reducing the emission intensity of private vehicles (through fuel and technology standards, as well as technical inspections) and providing additional and cleaner forms of public transport. In this last category, a key intervention in the three metropolitan areas under study is the implementation of Bus Rapid Transit systems (BRT) in Mexico City, Guadalajara, and Monterrey. In the remaining part of the paper, we outline methodological considerations for the evaluation of the mitigation co-benefits of BRT, and we propose a set of evaluation questions.

V. Methodological challenges for the evaluation of climate-related clean air policies: Research Opportunities

As Birnbaum and Mickwitz (2009) point out, environmental policies often address highly complex problems. This is the case of air pollution and climate change, which have multiple interacting causes and whose understanding is constantly redefined on the basis of progress in scientific research. As a consequence, clean air and climate change mitigation policies tend to be complicated –as they encompass a great number of interventions, actors and areas of expertise that need to be coordinated and integrated– and complex –i.e. characterized by a high degree of uncertainty about how to achieve policy objectives.[3] Clean air strategies and the climate change plans implemented in Mexico in the last decades fall in these categories, as they cut across different sectors and spheres of government, and require to be periodically updated to reflect advances in science and technology. As a consequence, the evaluation of these policies poses several methodological challenges, related to the different timing and scaling of impacts, data quality and credibility, and impact attribution (Birnbaum and Mickwitz, 2009).

As a first step to address these challenges, Mexico's Specific Guidelines and Criteria for Climate Policy Evaluation[4] establish a broad definition of impact evaluation. According to the aforementioned document, impact evaluation "analyzes the long-term effects, positive and negative, primary and secondary, intended or unintended, directly or indirectly produced by an intervention, with the purpose of determining its contribution to climate policy objectives and, when possible, changes that are attributable to its implementation".[5] In addition to evaluating the impact of specific interventions, "strategic evaluations" can be carried out at the policy level to evaluate the overall impacts of interventions implemented in different sectors and at different government levels and that contribute to the same policy objective.

In the following pages, we suggest evaluation approaches and methodologies to overcome the challenges outlined above, and to answer evaluation questions related to the ancillary benefits and costs of policies aimed at improving air quality.

VI. Attribution of mitigation co-benefits to clean air policies

The first challenge in evaluation is to attribute causality of emission changes to policy. This challenge arises from the absence of controlled environments in which we can observe the outcome variables with and without the effect of the policy but keeping everything else constant. In practice, this challenge boils down to finding a valid counterfactual with which we can compare data on the emissions levels that we observe under the policy. There are a few examples where randomized controlled trials can be implemented to serve this purpose. For example, Fowlie, Greenstone and Wolfram (2015) randomized an incentive to implement home weatherization with the purpose of increasing energy efficiency in U.S. homes. As homes that received the incentive were randomly

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[3] In this paper, the terms "complicated" and "complex" are used in the sense suggested by Patton, 2011 (p. 87-91) and Rogers, 2008 (p. 30-32).

[4] Specific Guidelines and Criteria for Climate Policy Evaluation set the basis for the country's climate policy evaluation framework and they were developed by the Evaluation Coordination, the Interministerial Commission on Climate Change, and the Climate Change Council. The document is available in Spanish on the following page: https://www.gob.mx/inecc/documentos/lineamientos-y-criterios-especificos-para-la-evaluacion-de-la-politica-nacional-de-cambio-climatico.

[5] Guideline 16, section IV. The definition of impact evaluation is based on the OECD-DAC definition of "impacts" (OECD-DAC, 2002, p. 24).

selected, it is statistically unlikely that anything else differed systematically between these and those who did not receive the incentive. Thus, households without the incentive made a valid control group with which energy use could be compared with.

Most of the time, policies that are likely to have an observable impact on emissions are necessarily large scale and randomization is often complicated in such scenarios. Thus, researchers rely on “natural experiments” to disentangle the causal effect of policy. The defining characteristic of a valid natural experiment is that it exploits a source of variation in the policy across subjects or observations that is unlikely to change the outcome variable through mechanisms outside the policy in question. Sources of variation in policy that are often used in the evaluation literature include the reliance on arbitrary rules that determine policy applicability, a quick comprehensive implementation, and the use of panel data (observations before and after the policy is implemented) combined with restricted applicability of the policy that results in an un-treated or control group. An example of the use of a quick comprehensive implementation is the evaluation of the first version of the driving restrictions program in Mexico by Davis (2008). This first version of the program, which was not linked to exemptions for new vehicles, became binding for all vehicles on a single day. This sudden implementation allows for a regression discontinuity design, which relies on other determinants of air pollution concentrations changing gradually over time. Davis compares pollution concentrations in the few days before and after the policy went into effect, finding no statistically significant difference. He also searches for changes in modes of transportation, finding no increases in more energy efficient modes such as public transportation. Although he does not directly address co-benefits, these results suggest that the policy had little causal impact on either criteria pollutants or GHG[6].

An example of the use of an arbitrary rule for eligibility in combination with panel data is the evaluation of the Clean Air Act Amendments in the U.S., which required non-attainment counties to implement more stringent policies to reduce criteria pollutants than attainment counties. In this case, the definition of attainment was based on an arbitrary standard in the average and maximum levels of air pollution (Chay and Greenstone 2005). Attainment counties with pollution levels that were close to the standard are a good control group for non-attainment counties that missed the standard by a small amount. Non-attainment and attainment status of counties in the U.S. have been used as a source of exogenous variation of air pollution policy in numerous studies. This research design is especially robust when comparing counties on either side of the non-attainment threshold, but very close to it as these counties are unlikely to differ substantially in any other air-pollution determinants (Chay and Greenstone 2005).

This evaluation design was also used in one of the few studies that target ancillary effects, or co-benefits as the main outcome of interest. Holland (2010) uses the eligibility rules in the Clean Air Act Amendments to explore the effect of criteria pollutant regulation on greenhouse gas emissions. He finds that non-attainment designation reduced carbon emissions by 30 percent. Furthermore, he finds that at least 60 percent of the reduction in carbon emissions can be attributed to a reduction in output.

A few other studies have evaluated co-benefits of air quality policy using the factor demand theoretical framework developed by Holland (2012). However, many of them lack the quasi-random variation in treatment that the Holland study has and therefore causality is not reliably established. For example, Li, Qiao and Shi (2016) look at co-benefits of SO_2 and soot removal for

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[6] The driving restrictions policy was subsequently linked to exemptions for new vehicles and to emission tests. The coupled policies have not been evaluated together.

China. The authors use a twenty-year panel data of 18 manufacturing sectors and evaluate whether SO_2 and soot are substitutes or complements of CO_2. The authors find that higher SO_2 prices cause output reduction, making CO_2 a gross complement of SO_2. Nevertheless, sharpest increases in soot removal had no effect on output reduction. It is worth highlighting that this paper relies on observed increases in pollutant removal for estimating pollutant interactions, which are assumed to be a policy response of firms. However, the quasi-experimental nature of these observed increases is hard to justify as unobserved confounding factors are hard to rule out in this context. For example, firms with the lowest soot removal could have had low investment all around, leading to output (and thus CO_2 emissions) that were lower relative to their high-soot-removal counterparts. This would have led authors to conclude that soot and CO_2 emissions are not complements, when the relationship observed in the data is not driven by environmental policy.

The second empirical problem arises from the difficulty in identifying spillovers to other sectors or other areas. In the case of the Clean Air Act, for example, some of the carbon emissions reduced in non-attainment counties could have been displaced to attainment counties. Because carbon emissions have the exact same effect regardless of where they are produced, displaced carbon emissions should not be accounted as emission reductions. Nevertheless, the research designs that exploit cross-sectional variation in policy stringency, like Holland (2010) and Li, Qiao and Shi (2016) can only measure carbon reductions relative to the control group (those who experienced less stringent regulation), which can lead to biased estimates of pollutant interactions. In light of this, many research papers have used computable general equilibrium (CGE) models. CGE models compute the relative changes in prices in inputs induced by a given regulation, in order to account for spillovers to unregulated sectors and areas and to feedback effects through price mechanisms (Liu et al. 2014, Changhong et al. 2006, Gielen and Changhong 2001 and Burtraw et al. 2003). The downside of CGE models, however, is that they rely less on empirical observations of firm behavior and often take the elasticities that characterize firm behavior from other empirical work that may or may not be the best suited for the specific context at hand.

In light of these considerations, the best context for a rigorous evaluation of policy impacts on multiple pollutants is one in which (a) the change in policy is arguably exogenous to firm's behavior and other determinants of emissions; (b) data quality is such that emissions and treatment (whether a firm or household has been subject to the regulation or not) can be correctly attributed to the corresponding units of analysis; and (c) there is little scope for treatment spillovers to control units and price changes at least over some time window for which data exists. These conditions allow researchers to reliably compute partial equilibrium effects of policy. General equilibrium impacts, whenever relevant, can potentially be computed by inputting these partial equilibrium effects into CGE models or by estimating structural models that allow for firm interactions in response to exogenous changes in policy.

VII. The importance of understanding context and pathways to impact

As pointed out at the beginning of this section, evaluation can and should be useful to identify a variety of impacts, which are produced at different times during and after policy implementation, as well as at different spatial scales; these impacts can be positive or negative, direct or indirect, first order or secondary, intended or unintended.

To identify these multiple impacts, it is crucial for evaluations to look at the context interacting with a policy or intervention, and to explain under which conditions that policy and intervention works (Garcia and Zazueta, 2015; Uitto, 2014). From a policy learning perspective, it is also crucial to analyze implementation processes in order to shed light on the mechanisms that have produced –or failed to produce- the expected impacts (Pawson & Tilley, 2013).

Data driven and qualitative methods can be combined to address these issues. One example of a qualitative methodology that is well suited for shedding light on pathways of impacts is Qualitative Comparative Analysis (QCA), which makes use of Boolean algebra to perform systematic comparisons among relevant cases. This method is helpful to identify conditions that can influence, individually or collectively, the attainment of the desired impact of a specific intervention (Befani, 2016). In the evaluation realm, QCA has been used, for example, to understand the factors facilitating or hampering the success of Information and Communication Technology-based reporting to improve sustainability in rural water supply (Welle at al., 2015). One advantage of this method is that it combines qualitative and quantitative analyses, taking advantage of their individual strengths, therefore enhancing the internal validity of the findings stemming from its application. Another advantage of QCA is that it is useful to identify the different combinations of conditions leading to the expected impact of one policy in different contexts (Fiss, 2012). However, it faces limitations related to the generalization of findings, the risk of over-simplifying qualitative information, and its reliance on the development of appropriate concepts and theories (Befani, 2016). The potential of this and other innovative evaluation methods should be explored further.

Qualitative methods can be combined with experimental and quasi experimental methods into mixed-method evaluation designs. As Bamberger et al. (2012) point out, “one of the advantages of mixed evaluation designs is to extend the comprehensiveness of evaluation findings, and thus to broaden and deepen the understanding reached as a result of an evaluation”(p. 324).

From this perspective, impact evaluation designs need to be matched to the nature of the intervention and the purpose of the evaluation; this approach is called “situational responsiveness” (Rogers, 2009). In this context, this means that different evaluation designs and methods might be available to the researcher given data and may be differentially suited to answer evaluation questions.

Hence, four key evaluation questions that are widely applicable across policies are:

1. What is the direct and attributable impact of specific interventions?

2. What are the aggregated impacts of interventions that contribute to the same objective? What are the linkages and synergies among these interventions?

3. Were there any indirect, secondary or unintended impacts?

4. How were impacts produced (or not), under what conditions, and for whom?

The implementation of Bus Rapid Transit systems (BRT) in the three major Mexican metropolitan areas will serve as the referred example to illustrate how to address some of the methodological challenges in answering these four questions.

Methodological considerations to evaluate the mitigation co-benefits of Bus Rapid Transit systems

The Government of Mexico City introduced the Bus Rapid Transit (BRT) system called “Metrobús” in 2002. Three years after its first operations, the Metrobús system was operating along 30 kilometers in its first corridor, otherwise known as Metrobús Insurgentes as it connected the North and South of Mexico City through Insurgentes Avenue. By 2016, the system consisted of 7 lines/corridors spanning over 125 kilometers with 208 stations across Mexico City. Metrobús is a registered Clean Development Mechanism, approved in 2014, comprising reductions of CO_2 and CH_4. At the design stage, the estimated emissions reductions were of 46,544 metric tonnes of CO_2 equivalent per annum.

“Macrobús” is the BRT system in Guadalajara, the second largest city in Mexico. Macrobús started operations in 2009 after being announced one year before. Nowadays, it covers 16 kilometers with 15 lines/corridors and 27 stations. Macrobús offers an express line in 12 stations that helps to reduce the congestion in rush hours and it is intended to reduce travel-time in half in the city.

Monterrey opened its own integrated bus rapid transit (BRT) known as “Ecovía” in 2014. Its service spans over 30 kilometers with 39 stations that cover directly three municipalities (Monterrey, San Nicolás, and Guadalupe), and indirectly, other three municipalities (Apodaca, García y Santa Catarina). Besides the implementation of the BRT, 47 connecting bus routes were restructured to utilize Ecovía as an axis for public transportation in this metropolitan area.

Quasi-experimental methods could be used in the evaluation of the GHG impacts of BRT (Question 1), as the policy affected some commuters more than others. First, a mode of transportation model estimated with the 2007 travel survey could determine the location of households less likely to change their behavior in response to BRT. The 2007 survey was collected several years after the first line of BRT was opened. Thus, one could estimate a mode of transportation model that allowed for preference heterogeneity based on the location of commuting routes relative to BRT.

This model would then be used to generate propensity scores for using BRT that incorporate newly existing lines. Propensity scores could be constructed at the census-block level using model estimates and geographic identifiers from the National Income and Expenditures (ENIGH) surveys, which also straddle the construction of the new lines. Propensity scores would allow the classification of ENIGH households into treatment and control units: units whose location makes their commuting choices susceptible to the introduction of BRT and households whose location makes BRT an irrelevant transportation alternative. Second, the rich consumption data and repeated nature of ENIGH could be used in combination with the timing of the different BRT lines to explore changes in fuel consumption as well as usage of different modes of public transport in treatment census-blocks relative to control census-blocks. Gasoline consumption and mode-specific fuel use could then be easily translated into CO_2 emissions.

Table 1 summarizes the expansion of Metrobús lines by date, and targeted population of each stage and matches ENIGH data by dates for possible evaluation of Mexico City BRT interventions.

Table 1: Mexico City Metrobús timeline and targeted population

Line	Opening	Kilometers	Mexico City affected municipalities	Users (thousands)	ENIGH available data
1	June 19, 2005/ extension: March 13, 2008	30	5	480	ENIGH 2004, 2005, and 2006.
2	December 16, 2009	20	4 y 1 State of Mexico municipality	180	ENIGH 2008 and 2010.
3	February 8, 2011	17	4 y 1 State of Mexico municipality	155	ENIGH 2010 and 2012.
4	April 1, 2012	28	2	65	ENIGH 2012 and 2014.
5	November 5, 2013	10	3	70	ENIGH 2012 and 2014.
6	January 21, 2016	20	2 y 3 State of Mexico municipality	150	

Source: Metrobús Historic Information [http://www.metrobus.cdmx.gob.mx/fichas.html

Note that the introduction of BRT has scope for spillovers and general equilibrium effects that may contaminate the evaluation design proposed above. For example, if the introduction of new lines changes the household decisions on where to live or where to work, emission reductions could occur in areas far away from the main lines as well. As GHG emissions would be evaluated in comparison with these areas, the estimated effects could underestimate the impacts. Structural models of commuting choices (e.g. Ahlfeldt et al. 2015, Severen 2016) could be used to assess location decisions and resulting changes in commutes.

Quasi-experimental methods can also be used to study the interactions with other policies (Question 2). In the case of BRT, a particularly interesting contemporaneous policy is the driving restrictions in México. According to a previous study (Davis, 2008), driving restrictions led to no impact on criteria pollutants and to increased used of taxis. There is also suggestive evidence that families purchased more vehicles (especially of used cars) in response to the regulation. However, increased access to public transportation in combination with driving restrictions has not been studied before. It could be that the new transportation alternative becomes the preferred way of transport for a large share of households on days when the main family car is restricted. However, it could also be that once the household has adapted by purchasing an additional vehicle, switching vehicles remains the preferred option to use on days when the main vehicle is restricted. Studying this behavior is complicated by the lack of high frequency data on transportation choices. However, one could obtain evidence on this behavior by exploiting the introduction of Saturday driving restrictions in 2008 and of consumption behavior from ENIGH on days when bad air quality triggered a doubling of the driving restrictions. The later would require implementation of enough ENIGH interviews coincide with the doubling of driving restrictions on dates that straddled the introduction of new BRT lines in the three studied cities.

Quasi-experimental methods can often be used to study unintended impacts of policy (Question 3). In the case of the study on driving restrictions (Davis, 2008) for example, there is some suggestive evidence that commuters switched to modes of transport that did not result in lower congestion or lower emissions. The same evaluation design, based on the sudden implementation of the policy, can be used to study some of this behavior (like the increased use of taxis). In the case of BRT, increased congestion from construction and lane reduction could result in additional criteria pollutant and GHG emissions. This unintended impact, however, would be hard to disentangle from the main impact as it would be reflected in additional gasoline consumption. The potential increase in criteria pollutants could be evaluated using air pollution concentration data from nearby stations. Bel and Holst (2015) conduct a difference in difference analysis and find that emissions were reduced in the neighborhood of BRT new lines.

Finally, the average causal effect of policy estimated from quasi-experimental methods can be decomposed by estimating the same effect for different groups based on pre-existing characteristics such as income and education. This type of heterogeneity analysis allows us to answer Question 4, shedding light on the distributional impacts of policy. Therefore, mixed methods approaches are promising to answer questions 3 and 4, and should be explored further in other opportunities.

VIII. Final remarks

Our analysis of the different air quality policies that, according to the theory of change, have large potential for co-benefits in the form of GHG reductions suggests that, given their important role in the generation of GHG, policies aimed at the transport sector should take priority for evaluation.

As it has been illustrated with the case of BRT, quasi-experimental methods can be used to answer key questions seeking to inform policy makers about the causal impacts of policies, including the case of ancillary benefits and costs. However, the use of these methods is greatly facilitated by the availability of data, a clear timeline and distinct eligibility rules, and little scope for spillovers and meaningful general equilibrium impacts. Quasi-experimental evaluation can be complemented by other methods, such as CGE models and structural models that could allow us to assess the spillover effects into other sectors or activities. Qualitative analysis can also enhance methods focused on causality by shedding light on the pathways and context within which quasi-experimental results are internally valid.

Going forward, richer data on (a) gasoline and fuel consumption of households and firms, (b) high frequency data on transportation choices, and (c) ground measures of CO_2 concentrations would facilitate the evaluation of the potential of mobile sources in the attainment of commitments established by the Climate Change Law in Mexico.

IX. References

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