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Report

Future air quality in Ha Noi and northern Vietnam

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Disclaimer

1.Introduction

Vietnam has made strong progress in economic growth and poverty reduction, and continues to transform from a rural to an urban economy. Accompanied by rapid urbanization, the country has recorded among the highest growth rates in the world, which in turn enabled swift reduction of poverty. At the same time, the fast economic growth in Vietnam's urban areas and the limited control of pollution are causing public health problems and significant environmental degradation, including air, water, land and greenhouse gases, which undermines the potential for sustainable socioeconomic development of the country with particular impacts on the poor. There is now ample evidence from epidemiological studies in Asia that exposure to PM2.5 is the most health damaging air pollutant and accounts for large attributable health burdens. The World Health Organization (WHO) as established a preferred guideline value for the annual mean concentration of fine particulate matter (PM2.5) in ambient air of 10 µg/m^3 together with a series of interim target levels that should guide countries on their way towards achieving the guideline value. The 2013 Annual Report on State of the Environment of the Ministry of Natural Resources and Environment(MONRE)reported high ambient levels of air pollution in many Vietnamese cities. For example, annual average levels of fine particulate matter (PM2.5) in Ha Noi were above 10 µg/m^3, compared with Vietnam's national air quality standard of 25 10 µg/m^3 (MoNRE 2013a). Without effective countermeasures, air quality is expected to further deteriorate in the future as a consequence of growing levels of polluting economic activities. However, world-wide experience clearly demonstrates that clean air can be achieved without compromising social and economic development. To be most successful, this requires well-designed policies that prioritize, for specific conditions, cost-effective interventions for the sources that deliver the largest benefits, and that are well integrated with other development targets. While there is ample experience from North America, Europe and other areas that could help improve the situation in Asia further, this cannot be directly transferred to Asia, due to differences in economic development, social conditions, meteorological factors and institutional settings. Identifying promising policy intervention options that could deliver effective improvements of in air quality in Asia together with progress towards the Sustainable Development Goals requires a holistic perspective that integrates geo-physical, economic, social and institutional dimensions across different spatial and temporal scales. Traditionally, such integration is less developed in the scientific world, hampering an effective interaction between science and decision makers. To this end, a cooperative scientific project has been established between the Vietnamese Academy of Science and Technology (VAST) and the International Institute for Applied Systems Analysis (IIASA), with the aim to develop a multi-disciplinary research community in Vietnam on integrated air quality management that could provide local decision makers with the capacity to develop cost-effective management plans that contribute to sustainable and equitable economic development. As a first step, IIASA's Greenhouse gas –Air pollution Interactions and Synergies (GAINS) model (Amann et al. 2011), a tool that is widely used across the world for the design of cost-effective pollution control strategies, has been adapted to capture the specific conditions of Vietnam, and implemented for the Greater Ha Noi/Red River Delta area and surrounding regions.

This report presents the results of the first year of the project. Section 2 reviews air quality management in the context of sustainable development. Section 3 provides a brief introduction of the methodology. To illustrate potential findings that can be derived from analyses with the GAINS-Vietnam tool once fully implemented with validated data, Section 4 presents initial outcomes obtained with the current draft implementation, keeping in mind that current data sets for the region have been constructed from publicly available data sources, international literature and global modelling tools. The Section reviews the understanding of the air quality situation in 2015 and how this would develop under current policy assumptions until 2030. It then introduces initial examples of the impacts of some alternative emission control strategies, comparing their impacts on emissions, air quality, population exposure and emission control costs. Conclusions are drawn in Section 5.

2. Air quality and sustainable development

Air pollution is an important risk factor for global disease burdens. It has a major impact on human health, particularly among the poor and vulnerable such as elderly and children. According to estimates by the World Health Organization (WHO), exposure to air pollution causes 6.5 million premature deaths annually worldwide (WHO 2016a). Nearly 90 per cent of these premature deaths occur in low-and middle-income countries, with close to two out of three in Asia and the Pacific.

The health risk posed by air pollution in Asia impacts urban and rural communities across several socio-economic tiers. The total mortality burden from household and ambient air pollution is ranked only fourth behind dietary risks, tobacco and high blood pressure. In 2013, it was estimated that exposure to ambient and indoor air pollution cost the world's economy about US$ 5.11 trillion in welfare losses. In South and East Asia this cost is equivalent to 7.4 and 7.5 per cent of their gross domestic product (GDP) respectively (World Bank 2016).

A focus on fine particulate matter (PM2.5)

There is now ample scientific evidence from epidemiological studies in Asia and the Pacific that exposure to PM2.5 is the most health damaging and accounts for large attributable health burdens. In this report, fine particulate matter is considered to be PM2.5 – particles with an aerodynamic diameter of less than 2.5 micrometres (µm). There is a variable relationship with PM10, particles with an aerodynamic diameter of less than 10 µm that may depend on the sources as well as the physics and chemistry of the atmosphere. The relationship may vary with location, season and weather conditions.

Sources of PM2.5 in ambient air

Fine particles are directly emitted during the combustion of fossil fuels and biomass including forest and peat fires, and from industrial processes; these particles include fly ash, various metals, salts, and carbonaceous species including black and organic carbon. Particle emissions also originate from natural sources such as soil dust and sea salt. Another substantial fraction of fine particles is formed in the atmosphere through chemical reactions involving gaseous emissions. Sulphur dioxide, nitrogen oxides and volatile organic compounds from fuel combustion and industrial processes, and ammonia from agricultural activities are the main contributors to the formation of fine particulates in this way.

Thus, any effective reduction of the health burden from PM2.5 needs to balance emission controls across all these source sectors. A focus on single sources alone will not deliver effective improvements, and is likely to waste economic resources at the detriment of further economic and social development.

The transport of PM2.5 in the atmosphere

The concentration of people, economic activities and energy demand in the world's growing cities means that poor air quality is often regarded as an urban problem. However, the physical and chemical features of fine particulate matter add an important spatial challenge to the air quality management task. Due to their small size and thermodynamic properties, PM2.5 particles remain in the atmosphere for several days, during which they are typically transported over several hundreds of kilometers. Thus, as a consequence, a significant share of particles found at any specific location originates from distant sources, which are often outside the immediate jurisdiction and control of the local authorities. Research shows that even in megacities (e.g., Delhi) about 60% of ambient PM2.5 found in the urban area emerges from pollution sources that are outside the immediate jurisdiction of the municipal administration (Amann et al. 2017).

Synergies with the Sustainable Development Goals

Provision of good living conditions including sufficiently clean air is an overarching policy objective that is also reflected in multiple Sustainable Development Goals, which address diverse and intersecting aspects of human and environmental needs and challenges. Achieving the SDGs by 2030 requires implementing coordinated and concerted strategies and actions that minimize potential trade-offs and conflicts and maximize synergies to contribute to multiple SDGs. Air pollution controls can contribute to the achievement of multiple SDG targets, including the reduction of greenhouse gas emissions (Haines et al. 2017). As countries seek to incorporate SDG implementation into their national policy and planning processes, it is important that multiple benefits are assessed to identify actions and strategies that can help achieve several SDG targets, while minimizing conflicts and trade-offs.

A non-exhaustive list of benefits includes, inter alia, accelerated infrastructure development (power grid expansion, loss reduction, enhanced gas distribution networks, waste management practices), time savings from avoided biofuel collection, additional jobs for the manufacturing of clean technologies (e.g., efficient and electric stoves, renewable energy), more efficient land use due to less ash and soot disposal, lower emissions of other toxic substances (Hg, POPs) with subsequent health benefits, improved traffic management, improve protection of historical monuments and buildings, and enhanced economic gains from tourism.

3. Method and data

As a consequence of the features discussed above, any cost-effective set of policy interventions to improve air quality in a city like Ha Noi needs to address emissions from a wide range of sources in many different economic sectors, not only within the city domain, but also in the surrounding provinces. This poses new challenges to environmental management and governance systems, where often necessary communication and coordination channels across-economic sectors and regional administrations are less developed. Such a process requires solid scientific information from a wide range of scientific disciplines, including technology research, economics, atmospheric science, and epidemiology, and needs to employ an integrative systems perspective

Modeling tools

The GAINS model

The analysis conducted for this assessment employs the Greenhouse gas – Air pollution Interactions and Synergies (GAINS) model tool (Amann et al. 2011) developed at the International Institute for Applied Systems Analysis (IIASA) – see Box 1.

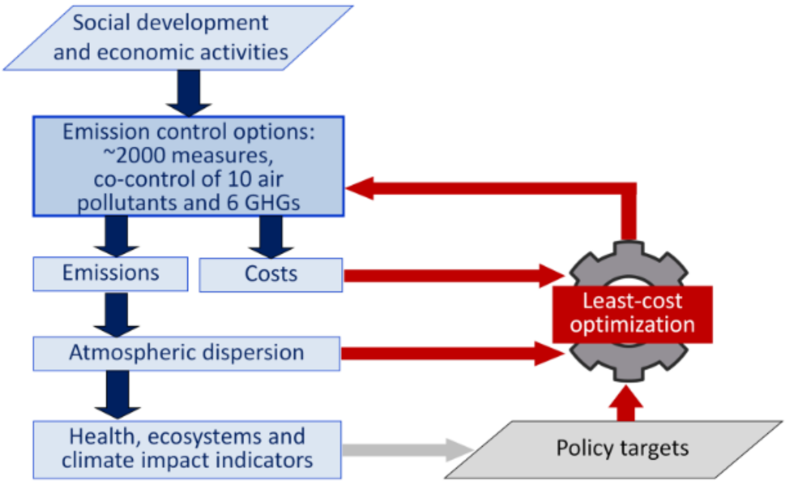
Based on scientific studies conducted in Vietnam, the model has been adapted to reflect the Vietnamese conditions, and fed with an initial set of data that reflects the Vietnamese situation as accurately as possible, while accepting the presence of critical information gaps. IIASA and VAST scientists have developed jointly a tool to import the energy and macroeconomic data and projections from the national model 'The Viet Calculator 2050' (see next section) into the GAINS model. This allows for seamless conversion and import of further scenarios developed by the VAST in the future.

The databases hold now information on alternative pathways of economic development developed by VAST, on their impacts on precursor emissions of ambient PM2.5, i.e., primary PM2.5, SO_2, NO_x, NH_3 and VOC, the technical potential for emission reductions at the various sources and associated emission control costs. Particular attention has been paid to information and data for craft villages, which are typical for the region and for which only poor statistical data exist. Furthermore, GAINS-Vietnam describes the atmospheric transport and chemical conversion of emissions across five regions, in order to assess the impacts of emission control measures on ambient concentrations of PM2.5 and population exposure throughout the region.

To explore the likely impacts of alternative policy interventions on emission reductions for Ha Noi and neighboring provinces, the study produced a series of source apportionments that estimate the current contributions of key sectors (e.g., power plants and industry, transport, residential combustion, agriculture) to ambient PM2.5 concentrations in the region. First, ambient PM2.5 concentrations have been estimated at the spatial resolution of $0.1^o \times 0.1^o$(approx. 11×10 km), with the sectoral emission estimates of the GAINS model and perturbation simulations of the EMEP atmospheric chemistry transport model of the long-range dispersion of pollution (Simpson et al. 2012). Subsequently, the contributions made by each individual emission source to ambient PM2.5 concentrations at a given receptor site have been extracted from the model calculations, and their impact on population-weighted exposure was calculated. The spatial emission distribution maps that underlie the atmospheric model simulations are presently based on globally available datasets. To refine the accuracy of the calculations in the future and increase the representativeness for the local conditions in the study area, it will be important to include local information on the spatial distribution of emission sources, particularly low-level sources like small scale industries which are not well quantified in international datasets.

Box 1: The GAINS model

The GAINS (Greenhouse gas-Air Pollution Interactions and Synergies) model explores cost-effective multi-pollutant emission control strategies that meet environmental objectives on air quality impacts (on human health and ecosystems) and greenhouse gases. GAINS, developed by the International Institute for Applied Systems Analysis (IIASA), brings together data on economic development, the structure, control potential and costs of emission sources, the formation and dispersion of pollutants in the atmosphere and an assessment of environmental impacts of pollution(http://gains.iiasa.ac.at).



GAINS addresses air pollution impacts on human health from fine particulate matter and ground-level ozone, vegetation damage caused by ground-level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition to soils, in addition to the mitigation of greenhouse gas emissions. GAINS describes the interrelations between these multiple effects and the pollutants (SO_2, NO_x, PM, NMVOC, NH_3, CO_2, CH_4, N_2O, F-gases) that contribute to these effects at the European scale.

GAINS explores, for each of the source regions considered in the model, the cost-effectiveness of more than 1000 measures to control emissions to the atmosphere. It computes the atmospheric dispersion of pollutants and analyses the costs and environmental impacts of pollution control strategies. In its optimization mode, GAINS identifies the least-cost balance of emission control measures across pollutants, economic sectors and countries that meet user-specified air quality and climate targets.

The Viet Calculator 2050

The 'Viet Calculator 2050' tool is an accounting demand-driven energy model(ISEA, MOIT 2016), which estimates the response of the energy supply system to changes in energy demand from different sectors. The tool facilitates energy planning, taking exogenous projections of the development of key macro-economic indicators as input and exploring four alternative trajectories of the penetrations of renewable energy and energy efficiency measures. The tool has been configured for Vietnam and transferred to the Ministry of Industry and Trade of Vietnam in 2014. As mentioned above, a conversion tool has been developed during this project that allows importing results from the Viet Calculator 2050 into GAINS.

Regions considered in the analysis

Although air pollution is often considered as a local urban problem, the physical features of PM2.5, especially its residence time in the atmosphere of up to one week, require analyses to extend over domains that cover most of the emission sources that contribute to population exposure within the region. Consequently, even with a focus on air quality in the Ha Noi metropolitan area, any scientific analysis must include emission sources in a much larger region, as Ha Noi's air quality is strongly influenced by pollutants from outside the city, and vice versa, Ha Noi's emissions affect air quality in a large surrounding area.

To this end, it has been decided to extend the model domain to all northern Vietnam, and group the provinces into five regions (Figure 1), which are then further considered in the analysis:

- Ha Noi province;
- Bac Ninh province;
- Hung Yen province;
- The Greater Ha Noi region and Red River Delta, i.e.,the Red River Delta and northern midland. This includes the provinces of Hai Duong, Bac Giang, Quang Ninh, Hai Phong, Thai Binh, Ha Nam, Nam Dinh, Ninh Binh, Thai Nguyen, Vinh Phuc, and Hoa Binh;
- The remaining areas of northern and northern central Vietnam, i.e., the provinces of Son La, Yen Bai, Lao Cai, Lang Son, Thanh Hoa, and Nghe An.

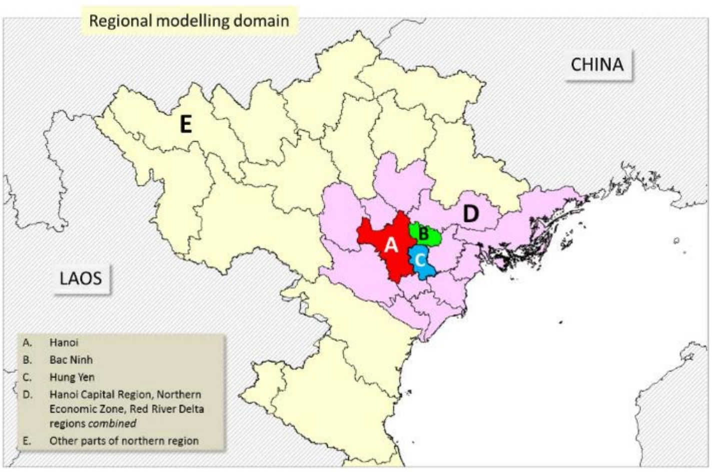


Figure 1 The regions distinguished in this analysis

Data collection for northern Vietnam

The GAINS model provides routines and default data for a wide range of emission sources, emerging from the experience that has been accumulated with GAINS model applications around the world over the last 30 years. While these encompass a wide range conditions under very different technological and development stages, they are not necessarily applicable to all emission sources that are important in Vietnam.

Within the first year of this project, IIASA and VAST researchers have jointly developed a GAINS compatible regional data set derived from provincial statistics on energy, transportation, agriculture, point source (power plants, large industrial facilities) data, and results of several national and regional studies and peer reviewed papers.

Energy use and industrial activities

Detailed provincial statistical data on energy use have been used along the databases from international sources (e.g., the International Energy Agency statistics (IEA 2015)and World Steel Organization data (WSO 2018)) to populate the GAINS database with energy balances at a regional level. In order to allocate power plants and industrial energy use, all power plants and key industrial complexes (iron and steel, cement, pulp and paper, fertilizer manufacturing plants, brick manufacturing) data were spatially identified and distributed to the regions considered in the GAINS-Vietnam model (see Section 3.2).Vietnam has been undergoing an important transition in fuel use structure for cooking. Several national and regional programs addressed solid fuel use (coal, wood, agricultural residues) by supporting the access to gas (liquid petroleum gas) for an increasing share of the population. The distributions of fuel use and fuel types by region drew on data and information summarized in national assessments (Hoang 2011; Accenture Development Partnership 2012). Further work utilizing more recent regional survey data is planned for the next stage of the project.

Road transport

Lacking the access to comprehensive data at the provincial level, road traffic activity data have been estimated at the national level and distributed to the regions based on suitable proxies. Fuel consumption was estimated from the number of vehicles(GSO 2006, 2016),average annual mileage and average fuel economy, relying on local measurements (NILU and CAI-Asia, CETIA 2015).The NILU, CAI-Asia, CETIA (2015) study was also used to develop the split of total fuel used in cars into gasoline and diesel. In total, the regional estimates of fuel consumption developed within this project match well, within 2-3%, the national statistical data for 2010 and 2015. However, differences to data held by the 'Viet Calculator' model are somewhat larger and need to be further explored.

Characterization of craft villages

There are about 1,450 craft villages in Vietnam, of which about 60% are located in Red River Delta (MoNRE 2008a). Businesses in these villages have greatly contributed to increased income and reduced poverty in rural areas. However, they have also caused severe environmental deterioration(MoNRE 2008a; Huy and Kim Oanh 2017).

They often waste resources and cause heavy pollution to air, water and soil, and are significant contributors to environmental pollution in rural areas. The specific conditions and features of the emission sources in such craft villages are likely to be only inadequately represented by international data (Huy and Kim Oanh 2017).At the same time, due to a lack of administrative capacity and human and financial resources, there is still a gap in the availability of data on craft villages for environmental impact analyses (Huy and Kim Oanh 2017).Only little quantitative data on activity statistics and characteristic emission factors from the various operations exist in Vietnam, so that currently all emission estimates for such sources drawing on partial and rather dated assessments are highly uncertain.

To improve the understanding of these sources and to facilitate more accurate emissions calculation, the VAST-IIASA project has developed a citizen-science approach to collect primary activity data from craft villages in Vietnam (Nguyen et al. 2018)through a mobile phone application. An interface with the GAINS databases enables the transfer of information emerging from the application of the mobile app. In October 2018, an initial data collection campaign involving 30 people including staff from CRETECH and students from the Ecological Club-University of Science and Technology of Ha Noi has been organized. After initial training, 10 groups of data collectors visited three to four craft villages, covering in total 34 villages including Bac Tu Liem, Nam Tu Liem, Dan Phuong, Hoai Duc, Ha Dong, Thanh Tri and Dong Anh (Figure 2).

However, as the data collection on draft villages is still under progress, emissions from craft villages are only included in this preliminary study to the extent that they are reflected by the currently available energy and economic statistics. There are strong indications that the current data strongly underestimate real emissions from these sources, so that especially for the rural areas the current estimates of emissions and ambient PM2.5 concentrations might be severely biased. This caveat also applies to the potential benefits from pollution control measures, which could be significantly higher.

Figure 2 Target regions of the initial data collection campaign for craft villages

Waste management

Historical activity data on industrial and municipal solid waste and wastewater generation, composition, collection rates and management practices have been derived from national statistics, official reports and scientific articles (GSO 1995; MoNRE 2008b; World Bank 2009; MoNRE 2010a; GSO 2011; MoNRE 2011; World Bank 2013; Nguyen and Chi 2015; GSO 2016; MoNRE 2016; DONRE 2018; URENCO 2018). Information related to the type of management of uncollected waste (scattered or openly burnt) carry larger uncertainty because usually such data is not included in the statistics which focus more on the management of the collected waste.

To further support and evaluate the assumptions and data used in the project the mobile phone application developed to collect data for craft villages (Nguyen et al. 2018) includes also information that can be used to characterize waste management practices. It is envisaged that the collected data will be evaluated in the next stage of the VAST-IIASA project.

Agriculture

In order to populate the regional databases in GAINS, historical data on livestock was collected from national and provincial statistics (GSO 2006, 2016)as well from more detailed data for dairy cattle and poultry (MARD 2018). For mineral fertilizers, the International Fertilizer Association (IFA 2018) statistics for urea and other nitrogen fertilizers were used, and distributed to the regions considered by GAINS-based on the share of cultivation land area by province (GSO 2006, 2016). Also data on rice cultivation area and production has been taken from the regional statistics (GSO 2006, 2016).

Large amounts of agricultural residues, primarily rice straw and husk, are generated in Vietnam, and are typically either open burned on the field or used as cooking fuel. Regional estimates of the volumes of residue burned on fields have been derived from recent data and review assessments (Oanh et al. 2011; Hoang et al. 2013; Dinh et al. 2016; Hoang et al. 2017; Kim Oanh et al. 2018).

4. Illustrative results

The scenarios presented in this section should be understood as preliminary illustrations of key features of the new GAINS-Vietnam modelling tool that is being developed within the current collaborative project between IIASA and VAST. While this report documents a first implementation of the tool for northern Vietnam, numerous aspects need further improvements. In particular, the current data set for Vietnam is based on information that is publicly available within the country, including energy statistics and emission data, or has been adapted from international data sources (e.g., atmospheric source-receptor relationships or energy statistics).

Before drawing robust conclusions that could guide decision makers in the design of effective air quality policies, all these aspects need further improvement –work that is foreseen in the second phase of the project. Also, a multi-disciplinary scientific community that brings together expertise on the many aspects that are relevant for an effective air quality management needs to be established in Vietnam, in order to initiate a long-lasting dialogue with decision makers.

Understanding of the current situation

To explore the scope and effectiveness of potential future policy interventions, the illustrative analysis starts from a detailed inventory of the current emission sources based on detailed spatial statistics. Data on pollution generating activities have been collected at the province level and point source information for power plants and large industries. Emission factors have been adjusted to reflect (to the extent local information is available) the Vietnam-specific technical features of the sources, and an inventory of already implemented and decided emission control measures has been compiled. Subsequently, the atmospheric dispersion calculation of GAINS has been used to compute the transport and chemical conversion of emissions in the atmosphere, with the aim to estimate the resulting fields of PM2.5 across the model domain, and calculate the resulting population exposure.

Emissions of PM2.5 precursor substances

Based on the regional activity statistics compiled by VAST, it is estimated that in 2015 about 253 kt of SO_2, 431 kt of NO_x, 188 kt of PM2.5 and 294 kt of NH_3 were emitted in the northern Vietnam model domain (Table1). However, it should be kept in mind that this initial data collation and emission estimate is hampered by imperfect information on local emission factors, and in particular by data gaps on craft villages(see Section 3.3.3). Further work is required to improve the accuracy of these initial estimates.

Most noteworthy, the relative contributions to total emissions differs significantly across the five sub-regions considered in the model analysis. For instance, power generation is most important in the remaining area of the Greater Ha Noi region, while itis absent in Ha Noi, Bac Ninh and Hung Yen. In contrast, transportation makes the largest contributions to NO_x emissions in Ha Noi, while emissions from the residential sector dominate PM2.5 in the other areas of northern Vietnam (Figure 4). As mentioned above, these initial estimates are likely to underestimate emissions from craft villages, especially in the Greater Hanoi/Red River Delta region.

Table 1 Initial estimates of precursor emissions of PM2.5 estimated for 2015 (kilotons)

	SO_2	NO_x	PM2.5	NH_3
Ha Noi	17.8	66.6	23.5	23.3
Bac Ninh	3.3	7.9	4.3	5.5
Hung Yen	2.5	7.7	4.7	8.2
Other Greater Hanoi/ Red River Delta	123.5	188.4	64.4	107.7
Other northern Vietnam	106.6	160.6	91.5	149.7
Total	253.7	431.2	188.4	294.4

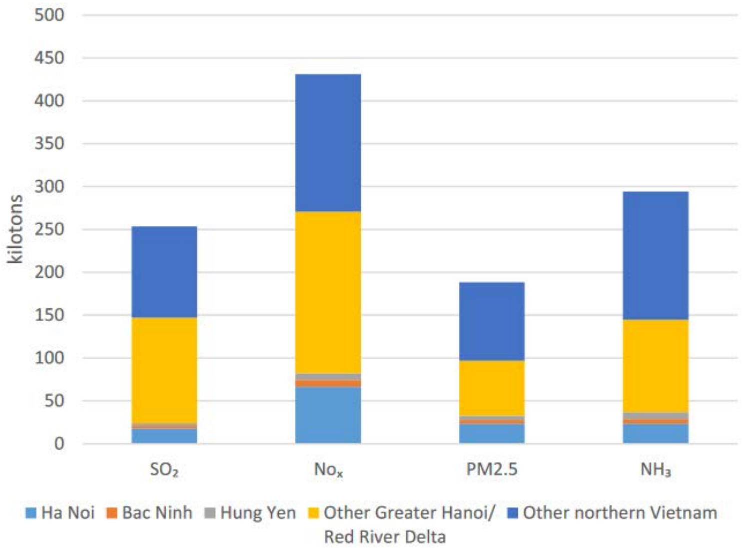


Figure 3 Emissions of PM2.5 precursors in northern Vietnam, estimated in this study for 2015, by region

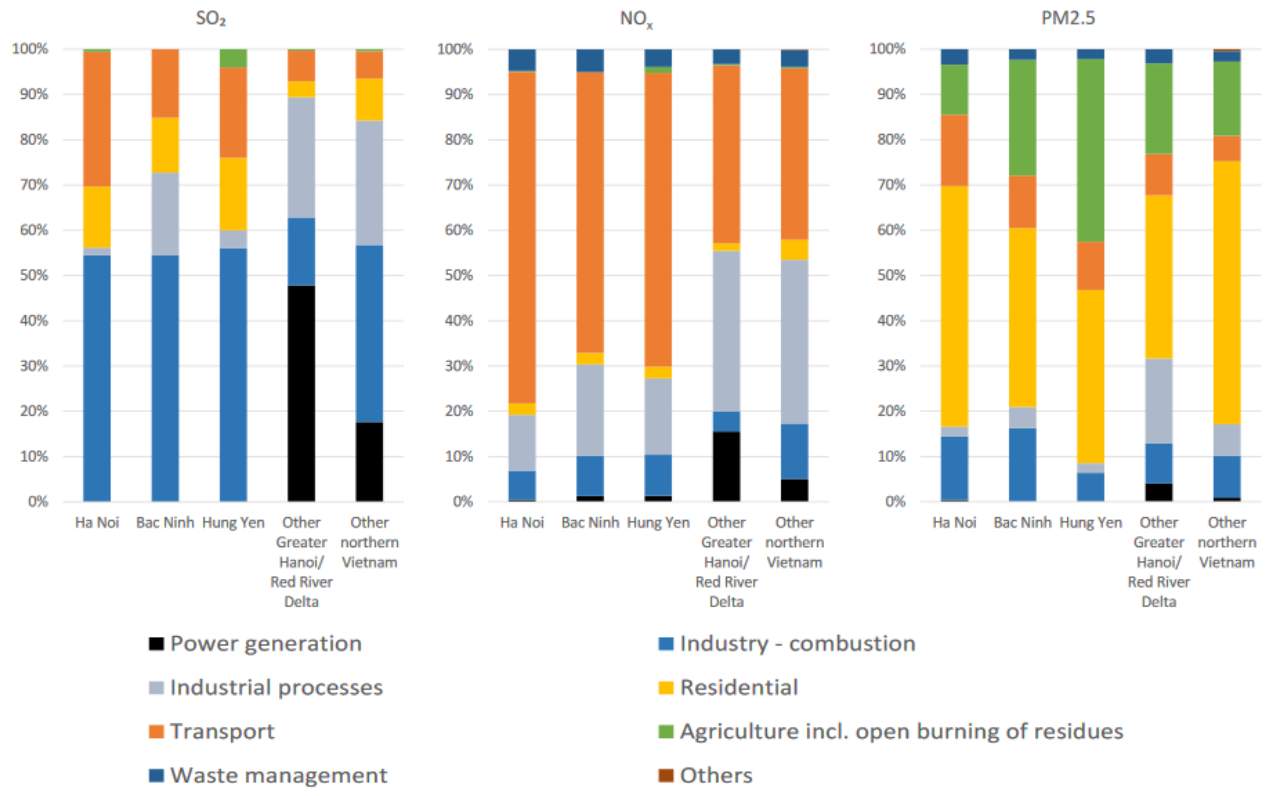


Figure 4 The relative contributions of different sectors to the precursor emissions of PM2.5 in the five regions, estimate for 2015

Ambient concentrations of PM2.5and population exposure

Based on these emission estimates for 2015, ambient PM2.5 concentrations across the northern Vietnam model domain have been estimated with the GAINS tool (Figure 5). Highest concentrations (up to 55 µg/m³) are estimated for the Ha Noi urban area. In the surrounding areas concentrations are lower although, as mentioned above, the lack of reliable emission estimates for craft villages could introduce a serious bias in these initial results. Few available studies measuring PM concentrations in rural areas suggest similar 24 hour average PM2.5 concentrations as in Ha Noi, e.g., in the north Vietnam rural mountain village of Tamdao (Co et al. 2014)and in Luc Nam, a village north-east of Ha Noi (Bac and Hien 2009). Nevertheless, even the current analysis suggests wide-spread exceedance of Vietnam's national air quality standard for PM2.5 of 25 µg/m³.

Given the uneven spatial pattern of ambient PM2.5 levels across Vietnam, the population exposure distribution is of interest for air quality management, in order to improve public health and to protect people from exposure above the national air quality standard (of 25 µg/m3). For 2015, the model analysis suggests that about 13 million people in northern Vietnam have enjoyed air quality that conforms to the national standard, while almost 20 million people were exposed to higher concentrations (Figure 6). Especially in the Ha Noi, Bac Ninh and Hung Yen provinces the national air quality standards were exceeded.

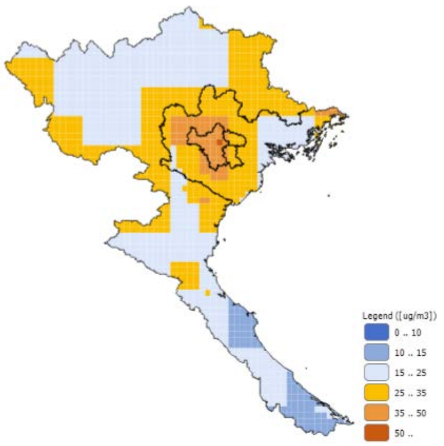


Figure 5 Ambient levels of PM2.5 modelled for 2015 (annual mean concentrations, µg/m³)

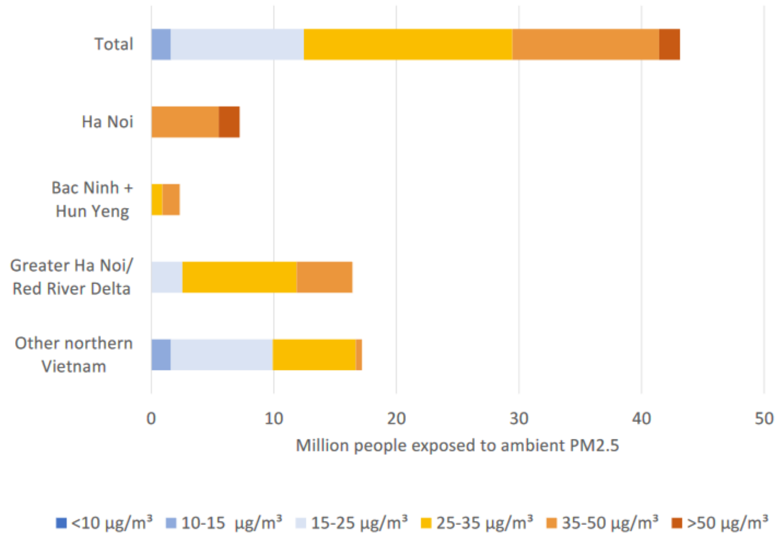


Figure 6 Distribution of population exposure to ambient PM2.5 in northern Vietnam in 2015 (initial GAINS estimates)

Validation

A robust validation of modeled ambient concentrations of PM2.5 is hampered by the scarce availability of quality-controlled long-term monitoring data of PM2.5, extending over entire years. However, the GAINS calculation is within the range of reported data (Table 2).

Table 2 Reported and modelled annual mean concentrations of PM2.5 for the Ha Noi metropolitan area ($\mu g/m^3$)

Data source	<2010	2012	2013	2014	2015	2016	2017
National Environmental Report 2016		33	52	43	45	35	
2013 Annual Report on State of the Environment (MONRE 2013)			>60				
(Cohen et al. 2010)	54 ± 33 (2001-2008)						
US Embassy						51	43
(Nguyen et al. 2015)			~60 (2010-2014)				
(Kim Oanh et al. 2006)	33-124[1)] (2001-2004)						
(WHO 2016b)						47.9	
This study: GAINS estimate[2)]	43-52 (2010)				42-55		

Notes: [1)] Averages for dry and wet seasons [2)] Variation across the metropolitan area in Ha Noi

Source apportionment

Most instructive, however, is the source apportionment that quantifies the contributions from the different emission sources and regions to ambient PM2.5 in a given region. For the Ha Noi (Figure 7, left panel), it is estimated that about one third of the population exposure to PM2.5 is caused by emissions within the city. One third is imported from the Greater Ha Noi /Red River Delta region, and the remainder from other provinces in Vietnam(8%), from other countries and international shipping(25%), and from natural sources (sea salt, soil dust, about 5%).In smaller regions with less emissions, the contributions from local emission sources are even smaller(see Figure 8for Bac Ninh and Hung Yen).

In contrast to wide-spread believe, road traffic is not the dominating source of PM2.5pollution in Ha Noi, although it contributes with about one quarter the largest share. About three quarters originate from other sectors. It is estimated that about 20% of PM2.5 in ambient air in the Ha Noi comes from large power plants and large industries, 15% is caused by emissions from the residential sector (cooking with biomass), another 15% from ammonia emissions from livestock farming and fertilizer application, and about 7% from the open burning of agricultural waste (Figure 7, right panel).

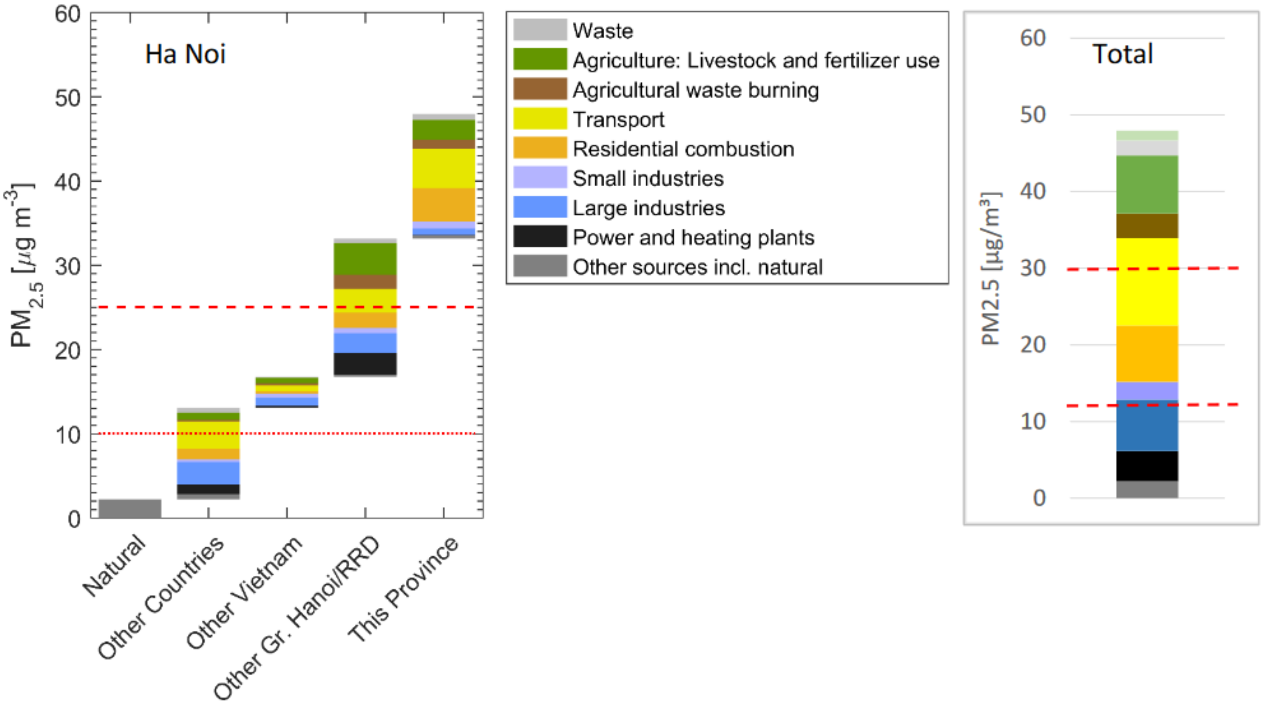


Figure 7: Sources of PM2.5 concentrations (population-weighted annual mean)in the Ha Noi in 2015. The x-axis distinguishes the spatial origin of PM2.5, i.e., (from right to left) (i) emission sources within the same province, (ii) sources in the other provinces in the Greater Ha Noi/Red River Delta region, (iii)Vietnamese provinces outside the Greater Ha Noi/Red River Delta region, (iv) sources in other countries and international shipping, and (v) natural sources (sea salt, soil dust).The y-axis indicates the amounts originating from emissions of the different economic sectors. The red lines indicate Vietnam's national air quality standard(25 µg/m³)and the global WHO air quality guideline for PM2.5 (10 µg/m³).

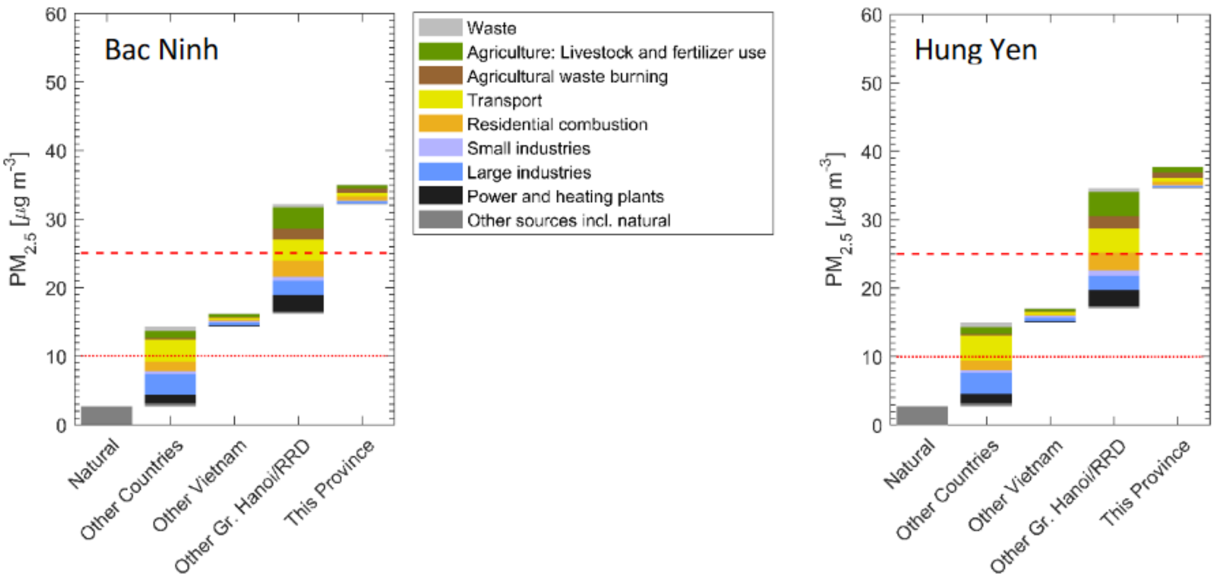


Figure 8: Source attributions to population-weighted PM2.5 concentrations in 2015 in the Bac Ninh (left panel) and Hung Yen provinces(right panel).Source categories as explained in Figure 7.

Future air quality

Vietnam is enjoying rapid economic development, which is also altering the driving forces for future pollution levels. In addition, the government is developing new regulations on emission controls that will benefit air quality in the future.

Economic development trends

To explore the likely future development of air quality in Ha Noi and the effectiveness of alternative policy interventions, a baseline projection of population, economic development and energy consumption has been developed with the 'Viet Calculator 2050' tool(see Section 3.1.2).

This projection follows the targets of the National Socioeconomic Development Plan (National Assembly 2016), with an annual GDP growth of 6.5-7%/year. By 2020, industry and services will account for about 85% of GDP. Population projections connect to the forecast of the General Statistic Office and UNFPA [5], foreseeing an increase in the urbanization rate up to 38-40%. These projections were complemented by the Vietnam Energy/Renewable Energy Development Strategy to 2020 with vision to 2050 (Prime Minister TD 2007; Prime Minister 2015), the Vietnam Green Growth Strategy to 2030 with vision to 2050 (Prime Minister 2012)and sectoral development plans for agriculture, industry and transport. The regional distribution of economic growth is based on the provincial developments plans.

Overall, the projection assumes an annual population growth in northern Vietnam of 0.7%/year, resulting in 2030 in a 11% larger population than in 2015. At the same time, economic wealth (expressed as GDP/capita) will improve by 5%/year, which will increase total economic output (GDP) by 130% in 2030(Figure 4). Transport demand is assumed to follow the same growth path. The economic projection is accompanied by an energy forecast that predicts a decline in energy intensity in the Ha Noi, Bac Ninh and Hung Yen provinces, and increased intensity in the Greater Ha Noi/Red River Delta area due to the shift of industrial activities to this region (Table 4).

Table 3: Assumed development of key indicators between 2015 and 2030.

	Population (million people)			GDP/capita (1000 €/yr)			GDP (billion €)		
	2015	Annual growth rate	2030	2015	Annual growth rate	2030	2015	Annual growth rate	2030
Ha Noi	7.22	0.9%	8.23	1964	5.1%	4129	14.2	6.0%	34.0
Bac Ninh	1.15	1.0%	1.35	2776	3.6%	4687	3.2	4.6%	6.3
Hung Yen	1.16	0.7%	1.29	1030	5.3%	2230	1.2	6.0%	2.9
Other Greater Hanoi/ Red River Delta	16.41	0.5%	17.77	640	5.0%	1329	10.5	5.5%	23.6
Other North Vietnam	17.19	0.9%	19.59	545	5.1%	1152	9.4	6.0%	22.6
Total	43.14	0.7%	48.24	891	5.0%	1853	38.45	5.8%	89.38

Table 4: The development of transport demand (10^9 vehicle kilometers), energy intensity (PJ) and electricity consumption (PJ) in the baseline scenario (Source: Viet Calculator 2050)

	Vehicle mileage			Energy intensity			Electricity consumption		
	2015	Annual growth rate	2030	2015	Annual growth rate	2030	2015	Annual growth rate	2030
Ha Noi	11.28	4.2%	20.95	13.6	-0.8%	12.1	29.98	10.4%	131.96
Bac Ninh	0.96	3.7%	1.65	6.8	-0.1%	6.7	5.44	10.1%	22.89
Hung Yen	0.87	3.4%	1.44	18.1	-1.4%	14.6	5.47	10.1%	23.09
Other Greater Hanoi/ Red River Delta	14.76	3.4%	24.35	81.1	2.0%	109.1	47.92	9.4%	184.24
Other North Vietnam	12.16	3.4%	19.99	68.5	-0.1%	67.8	141.02	9.9%	578.73
Total	40.03	3.6%	68.38	45.0	0.9%	51.5	229.83	9.9%	940.91

Table 5: The development of fuel consumption (PJ) in the baseline scenario (Source: Viet Calculator 2050)

	Coal, biomass			Liquid fuels			Natural gas		
	2015	Annual growth rate	2030	2015	Annual growth rate	2030	2015	Annual growth rate	2030
Ha Noi	58.8	-3.4%	35.1	104.0	5.8%	243.3	0.12	5.8%	0.28
Bac Ninh	8.9	-3.4%	5.3	7.2	4.4%	13.8	0.02	6.3%	0.05
Hung Yen	8.9	-3.5%	5.2	7.2	4.3%	13.5	0.02	6.3%	0.05
Other Greater Hanoi/ Red River Delta	693.9	8.0%	2192.3	110.6	4.0%	200.1	0.16	1.5%	0.2
Other North Vietnam	348.5	3.9%	617.9	150.6	5.4%	331.7	1.13	6.0%	2.72
Total	1119.1	6.4%	2855.9	379.7	5.1%	802.3	1.45	5.6%	3.3

Pollution control legislation considered in the baseline

The Vietnamese authorities have imposed regulations on important emission sources (see Table 6) that should lead to significant improvements in ambient air quality. Eventually, these should achieve compliance with the national air quality standard of 25 μg/m³annual mean PM2.5 (MoNRE 2013a)and the international air quality guidelines of the World Health Organization. Further regulations are under discussion.

As a starting point, a 'Current Legislation' (CLE) scenario developed for this study explores the interplay between pollution control policies and economic growth and their impact on future air quality. This scenario assumes the economic development trends outlined above with a timely and effective implementation of the current legislation on pollution controls as described below.

For road vehicles, Vietnam has been following the European emission standards and testing procedures. For a long time, Euro 2/II has been the emission standard applicable to new registrations, both light and heavy duty vehicles. This has recently been tightened to Euro 4 emission standards for gasoline cars and Euro 5/V for diesel vehicles, accompanied by improved fuel quality standards, a reduction of the sulfur content. However, fuels with higher sulfur contents are available in parallel which might jeopardize the full and durable functioning of the vehicle emission controls. Remaining Euro 5/V emission standards are scheduled for introduction in 2022-23. Non-road machinery remains essentially uncontrolled. In the 'Advanced Control Technology' (ACT) scenario we assume that Euro 6/VI emission standard for road vehicles will be introduced from 2028 onwards.

Table 6: Air pollution control policies in Vietnam considered in the Current Legislation (CLE) baseline projection.

Sector	Current status	Future regulations
Thermal power plants	• Regulation from 2009 (MoNRE 2009a)	
Industry	• Pollution regulations issued in 1995 • 2009 updates for dust and inorganic substances (MoNRE 2009b) • Chemical fertilizer plants (MoNRE 2009c) • Cement plants (MoNRE 2009d) • Oil refineries (MoNRE 2010b) • Steel industry (MoNRE 2013b)	
Road transport	• Euro 2/II for light duty and heavy duty vehicles, gasoline and diesel – until 2018	• Euro 4/IV - since 2018 • Euro 5/V - from 2022/23 onwards

The current legislation baseline case in 2030

Following the regional economic trends of the underlying energy projection and assuming effective implementations of the emission controls listed in Table 6, ambient PM2.5 concentrations would slightly increase throughout northern Vietnam up to 2030, compared to the current levels. Computed maximum concentrations of PM2.5 would grow from from 55 μg/m³ to 64μg/m³ (Figure 9, left panel),which is more than twice above Vietnams national air quality standard. Most importantly, such high concentrations would not only prevail in the city area of Ha Noi, but new areas with high concentrations would emerge from new industries in the Greater HaNoi/Red River Delta region.

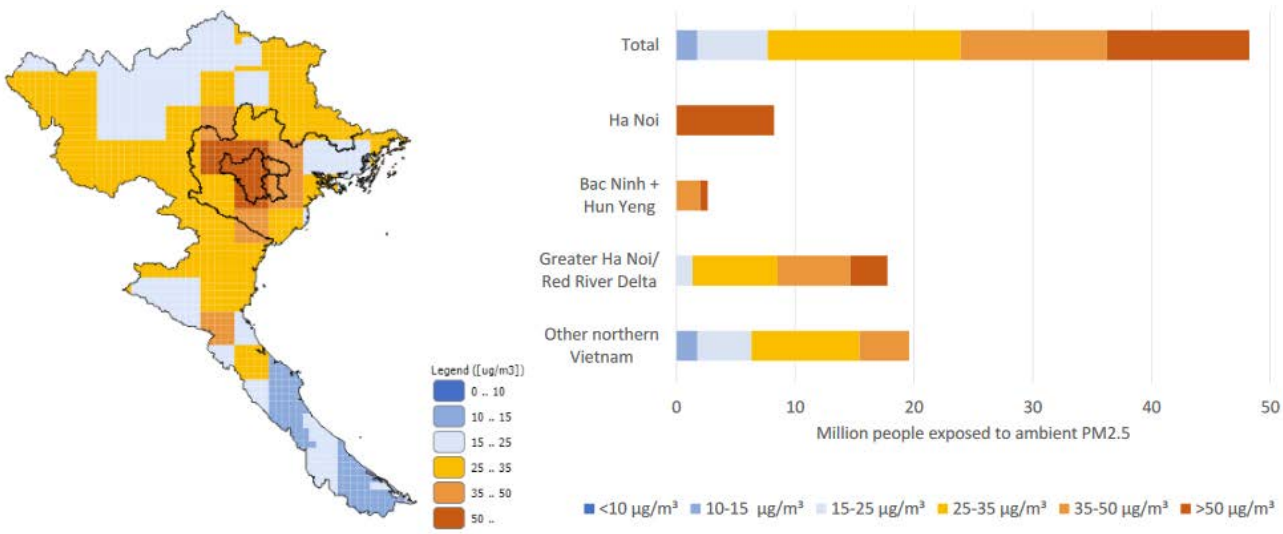


Figure 9: Ambient concentrations (left panel) and population exposure (right panel) for PM2.5 in the current legislation baseline case in 2030.

Population-weighted PM2.5 concentrations would rise in the Ha Noi by more than 20% up to 58µg/m³, and even more in relative terms in the Bac Ninh and Hung Yen provinces. This would also worsen the population exposure, and only 7.7 million people would live in areas where PM2.5 is below the national air quality standard, 38% less than in 2015. Conversely, the number of people exposed to concentrations above the standard would increase by 50%, i.e., to 28 million people in 2030 (Figure 9, right panel).

As emission growths are similar in all regions, the spatial source apportionments do not change drastically over time in relative terms (Figure 10).Compared to the situation in 2015, the largest increase in ambient PM2.5 is expected to come from emissions in the power sector.

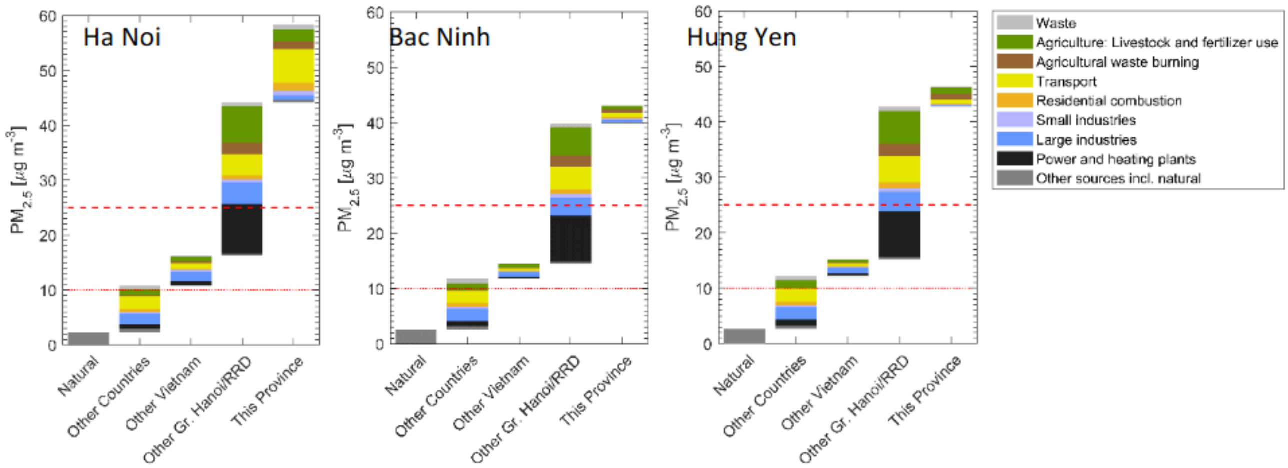


Figure 10: Source apportionment for the current legislation baseline projection in 2030. The graph shows the contributions to population-weighted PM2.5 concentrations in the Ha Noi (left panel), Bac Ninh province (centre panel) and Hung Yen province (right panel).

The scope offered by advanced emission control technologies

As a logical extension of current policies, an illustrative 'Advanced Technology' case assumes strengthened measures that rely on technical emission controls, in line with examples widely adopted in many other countries in the world. However, this scenario does not consider the potential benefits from further structural changes in the economy that affect the levels of the most polluting activities, such as the burning of coal and biomass, e.g, through energy conservation or substitution of fuels. As will be indicated later, such measures offer significant potential for air quality improvements, in addition to their benefits on other development objectives.

For the analysis presented in this paper, such a scenario would tighten the emission limit values for large point sources for SO_2, NO_x and PM/TSP. For mobile sources, tighter controls would be introduced for non-road mobile machinery, and emission standards for road vehicles would progress to the Euro6/VI level. However, this scenario does not assume premature scrapping of existing capital stock and equipment, so that cleaner technologies penetrate the market only through capacity expansions or in the course of regular replacement of outdated equipment.

To illustrate the importance of regional cooperation, two sensitivity cases are computed. Following the argument that currently PM2.5 levels are highest within the Ha Noi urban area, the first case simulates an urban approach to clean air management in which the advanced control technologies would be only applied to emission sources within the Ha Noi.

As to be expected from the source apportionment for the baseline projection in Figure 10, such an urban response policy could deliver only limited responses in pollution levels within the Ha Noi. Maximum ambient PM2.5 concentrations are computed to decline from 64μg/m³in the baseline to 56μg/m³, and population mean exposure to 52μg/m³ within the Ha Noi (Figure 11,left panel).

In contrast, the second case assumes advanced technical controls throughout the entire Greater Ha Noi/Red River Delta region. Such an approach could reduce maximum ambient concentrations of PM2.5 (in Ha Noi city) to 35μg/m³ , and mean population exposure in Ha Noi to 33μg/m³(Figure 11, right panel).

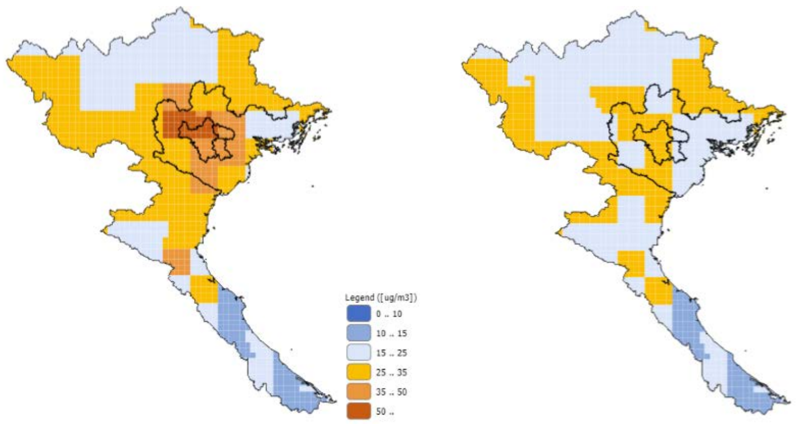


Figure 11: Ambient concentrations of PM2.5 from applying advanced technical controls(ACT)in Ha Noi (left panel) and advanced technical controls throughout the Greater Ha Noi/Red River Delta

The limited effectiveness of local emission controls for a pollutant that resides in the atmosphere for up to one week is clearly shown in Figure 12 where the largest reductions in ambient levels in Ha Noi are brought about by measures in the wider surroundings.

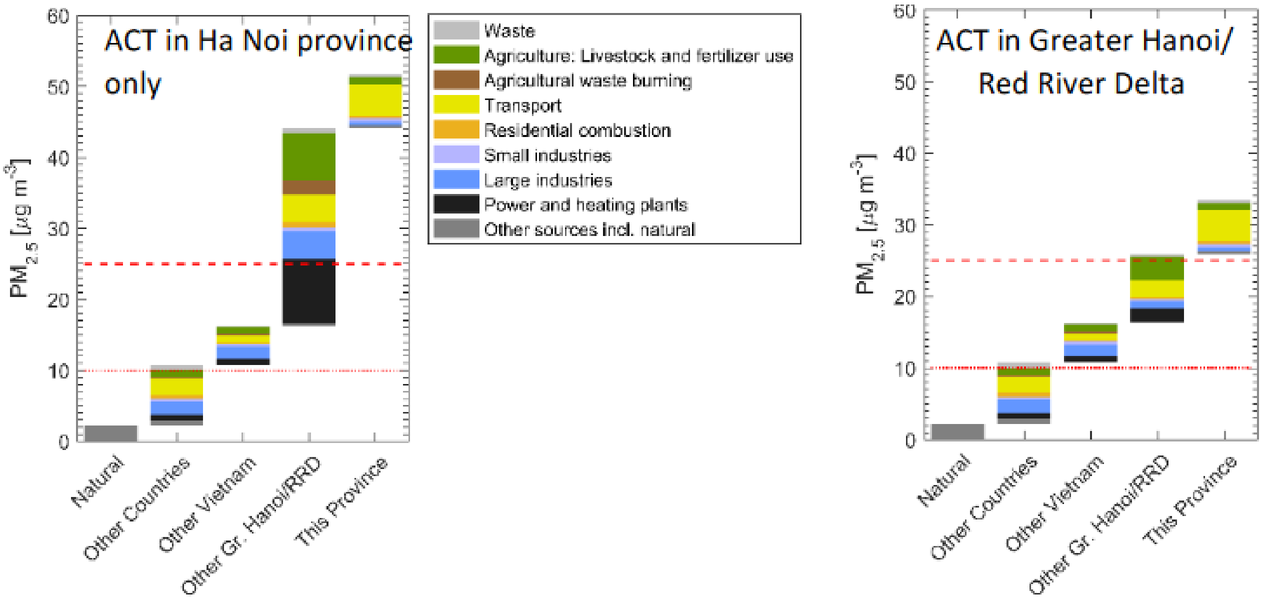


Figure 12: Source contribution to population-weighted PM2.5 in the Ha Noi in 2030 for the 'Advanced Technology' set of measures applied to Ha Noi (left panel) and in all of Northern Vietnam (right panel)

Co-firing of biomass in the power sector

While the above cases provide an initial example for the analysis of the scope of technical emission control measures, a second group of policy interventions could improve air quality through changes in energy, industrial and agricultural policies. As an initial example, this report presents an analysis of a strategy to utilize rice straw residues for co-firing in coal power plants.

The current management practices of rice residues in Vietnam, i.e., mostly open burning of crop residues, contributes significantly to air pollution by emitting significant amounts of pollutants such as PM, SO_2 and NO_x as well as greenhouse gases (CO_2, CH_4) (Nguyen 2012; Hoang et al. 2013; Dinh et al. 2016; Hoang et al. 2017).

Instead of burning agricultural residues on the field, rice straw could be used for co-firing in coal power plants. This would deliver a number of benefits on air pollution. Although the quantities of agricultural waste burned are the same, air pollutant emissions could be significantly reduced due to higher combustion efficiencies and effective filtering the air pollutants with the standard devices (in addition, rice straw contains less sulphur than coal). A recent study found that in Vietnam co-firing of rice straw in power plants, thereby substituting five percent of the coal input, could reduce PM10, SO_2 and NO_x emissions by 10-14%, 5-8% and 4.5%, respectively. At the same time, this could reduce greenhouse gas emissions by about three percent (Truong and Ha-Duong 2018b).

To explore the potential impacts on air pollution in the northern Vietnam region, an illustrative scenario was developed in which in 2030 five percent of the coal used for power generation would be substituted by rice straw biomass. At the same time, the amount of the rice residue burned on the fields will be reduced proportionally.

We also assume that the residues can be transported from one province to another within the study region, and that emissions from such transport are negligible compared to the avoided emissions from combustion (Truong and Ha-Duong 2018a).As there are no coal power stations in the Noi, Bac Ninh, and Hung Yen provinces, we assume that rice residues from these provinces can be transported to the closest power plant outside of these provinces. The initial GAINS analysis indicates significant air quality benefits from such a strategy. This single measure would reduce maximum concentrations of PM2.5 in Ha Noi from 64 µg/m^3 in the current legislation baseline case to about 58µg/m^3. Mean population exposure would shrink by about 7%.

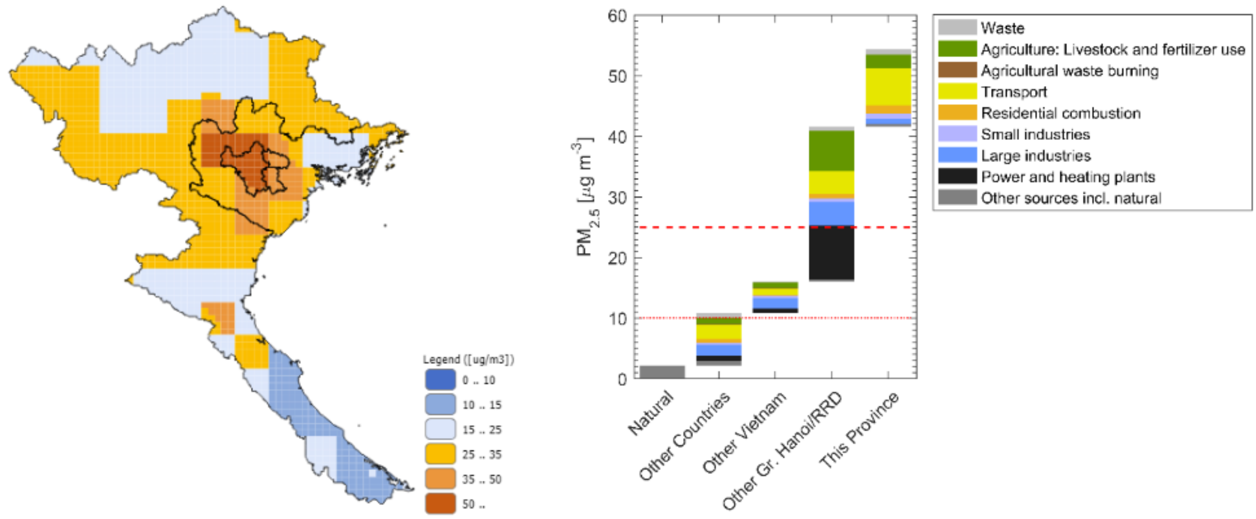


Figure 13: Ambient concentrations of PM2.5 resulting from the substitution of five percent of coal by rice straw residues in the power sector (co-firing) in 2030and the source contribution in the Ha Noi.

Comparison of emissions, population exposure and costs

The policy intervention options discussed above result in different emission reductions of PM2.5 precursors in the various regions in northern Vietnam, which in turn have different impact on population exposure because of differences in climatic, meteorological and topographic conditions as well as in population densities. The impacts of the measures on emissions in the Greater Hanoi/Red River Delta region are shown in the next section.

Emissions

In the Greater Hanoi/Red River Delta region, the ACT scenario would have the largest impact on PM2.5 emissions, as measures are affected for all sectors. This is followed by the Co-firing scenario, where the main reductions occur in agricultural waste burning, although the strategy in itself focuses on a reduction of coal consumption (Figure 14).

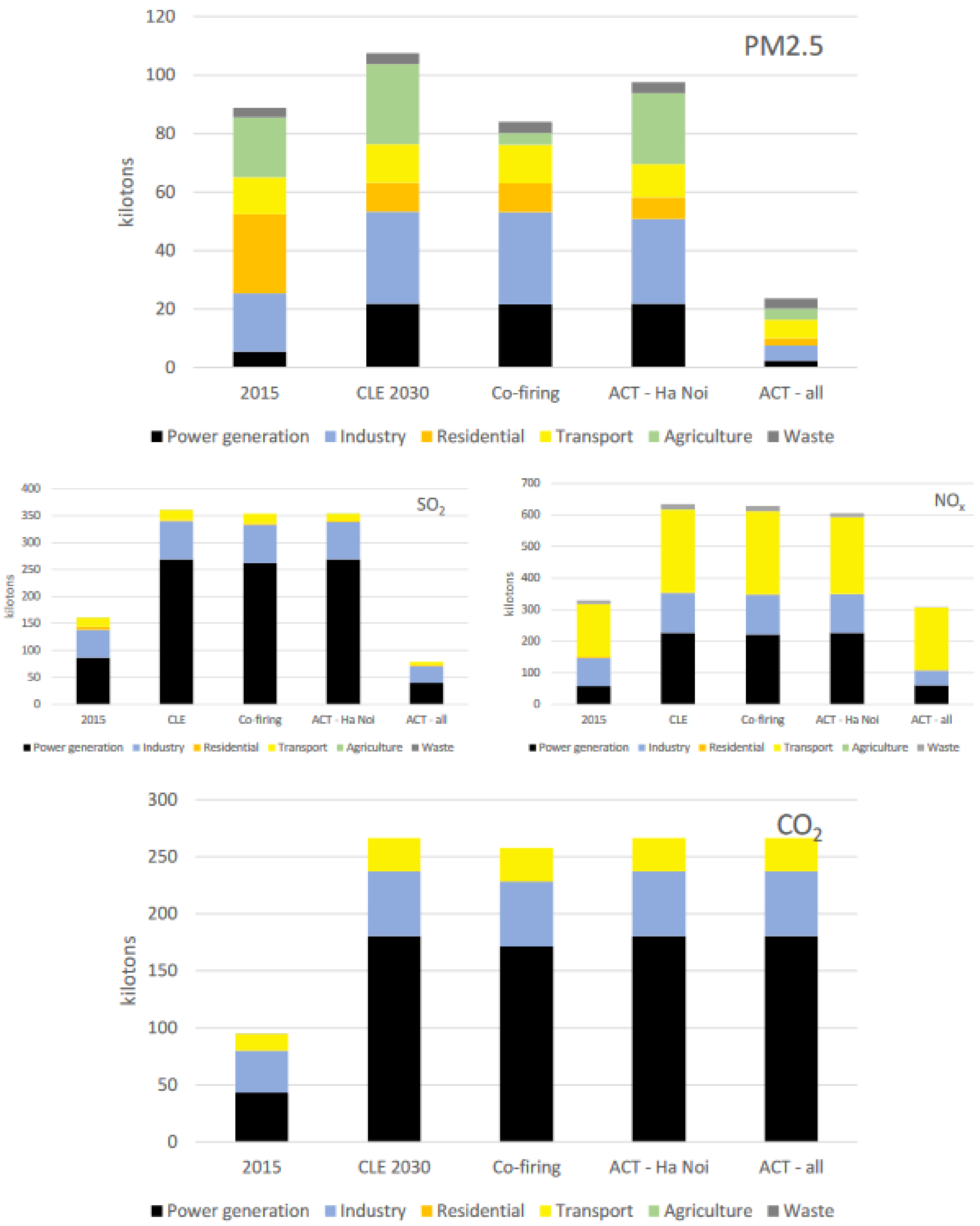


Figure 14: PM-precursor emissions in the Greater Ha Noi/Red River Delta region, for 2015 and 2030 for the scenarios discussed in this report.

Population exposure

For population exposure, Advanced Control Technologies applied throughout northern Vietnam would make the largest improvements too. Such a strategy could deliver air conforming to the national air quality standard to 25 million people, more than half of the total population (Figure 15).

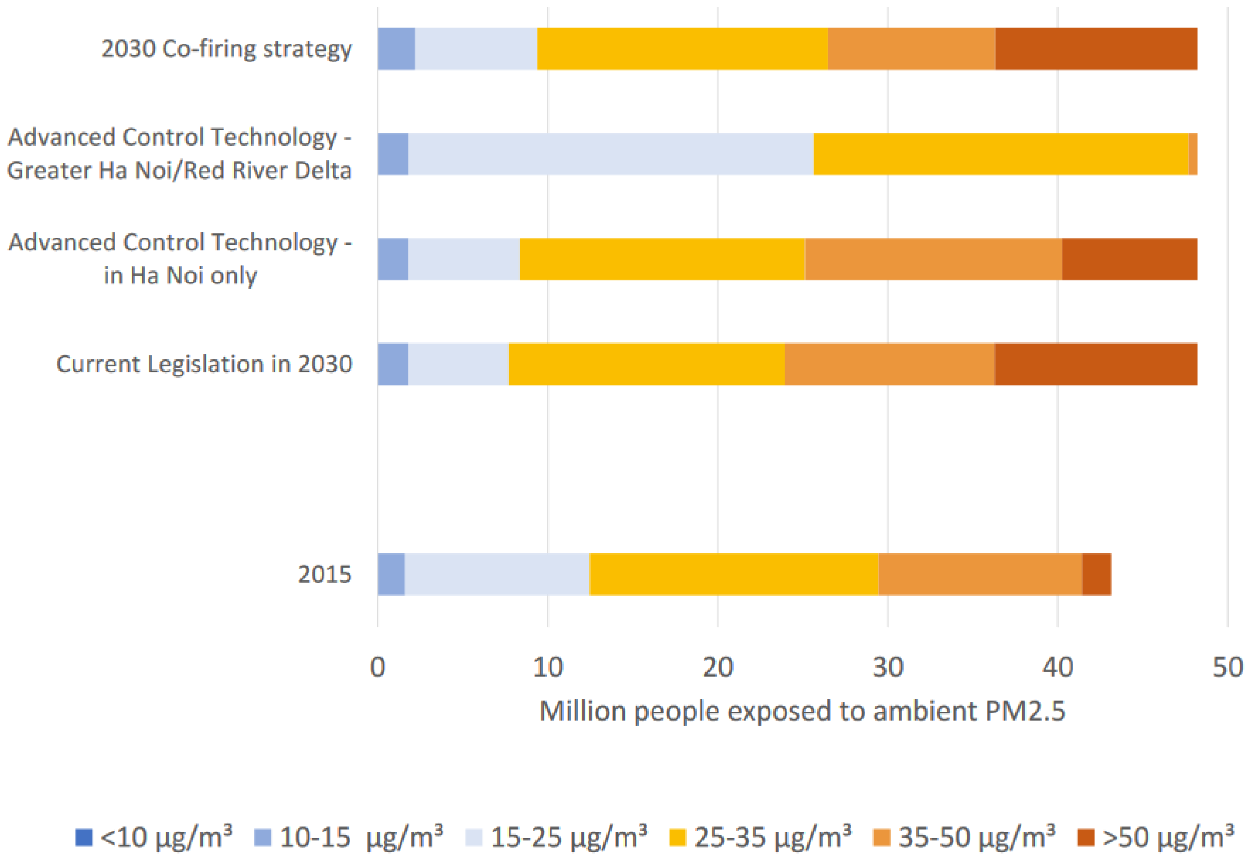


Figure 15: Distribution of population exposure to ambient PM2.5 in northern Vietnam for the different emission scenarios

Emission control costs

Based on current data in the GAINS-Vietnam model, it is estimated that in 2015 Vietnam spent about 1.5% of its GDP on air pollution controls, most of it for vehicle emissions (Figure 16). Implementation of the additional emission controls that are already decided (CLE) will increase costs in the future, and they would account for 2.1% of GDP in 2030. Full implementation of the Advanced Control Technologies (ACT) would require significantly higher resources; if applied in Ha Noi only, would increase costs to 2.3% of the GDP of the Greater Hanoi/Red River Delta region, and application throughout the Greater Hanoi/Red River Delta region to about 3.7% of GDP. In contrast, costs of the co-firing strategy that does not target on expensive emission control technologies but recycles agricultural waste as a substitute for coal in the power sector are even lower than those of the current legislation (2.0% of GDP).

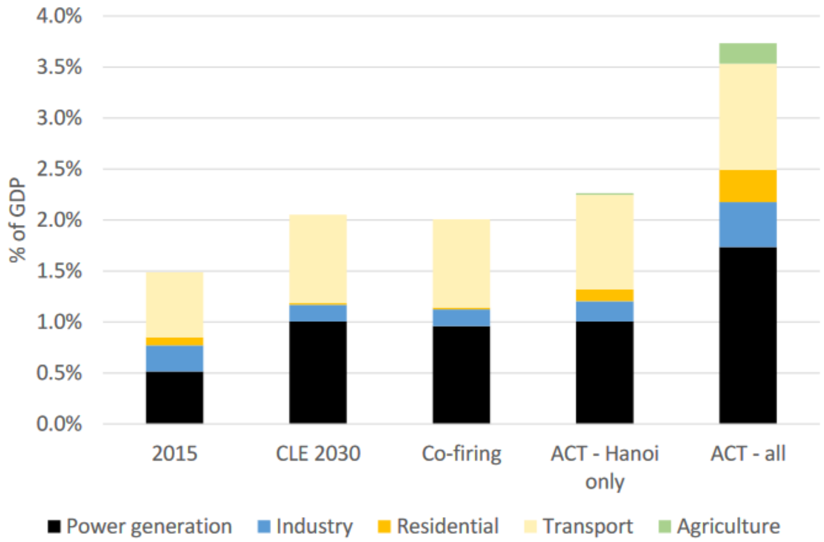


Figure 16: Air pollution control costs for the different scenarios, as percentage of GDP

Cost-effective air quality management strategies

The differences in the key features of the illustrative scenarios discussed above, i.e., (i) the benefits on ambient pollution levels and population exposure, as well as (ii) air pollution control costs indicate a significant potential for the development of cost-effective strategies to improve air quality without putting excessive burdens on the economy. The GAINS-Vietnam model, for which a first version has been implemented in the joint VAST-IIASA project, provides a powerful tool for the analysis of such cost-effective strategies based on best scientific information that could provide useful information for decision makers in Vietnam.

5.Conclusions

To explore management options to improve air quality in northern Vietnam and deliver a wide range of development benefits, the collaborative project between VAST and IIASA developed an initial version of the GAINS-Vietnam tool.

While the underlying GAINS methodology is being applied for practical policy analyses throughout the world, many of the Vietnam-specific input data that have been compiled in the first year of the project are still imperfect and need to be further improved and validated. Also, the economic analysis features of GAINS that allow estimating costs of alternative pollution control strategies, the development of cost-effective policy response packages, and the consideration of the socio-economic heterogeneity will need to be further tailored to the Vietnam situation.

During the first year of the project, the tool has been adapted to northern Vietnam, and an initial set of data has been compiled from publicly available statistics and studies. Despite the interim nature of the initial version, a range of conclusions can be drawn that offer highly relevant information for air quality management in Vietnam.

Poor air quality is an important development issue in Vietnam

Poor air quality is a major development burden, with significant impacts on public health. According to estimates by the World Health Organization (WHO 2016a), exposure to air pollution causes 6.5 million premature deaths annually worldwide. Nearly 90 per cent of these premature deaths occur in low-and middle-income countries, with close to two out of three in Asia. Welfare losses from exposure to high pollution are significant, equivalent to up to 7.5 percent of the GDP in East Asia (World Bank 2016). In Vietnam, the measured annual mean concentrations (typically between 35 and 60 μg/m^3) are clearly above the national air quality standards of 25 μg/m^{3}and exceed the global guideline value of the World Health Organization (10 μg/m^3) by a wide margin.

GAINS-Vietnam: A systems perspective to support cost-effective air quality management

World-wide experience clearly demonstrates that clean air can be achieved without compromising social and economic development. However, identifying promising policy intervention options requires a holistic perspective that integrates geo-physical, economic, social and institutional dimensions. To develop a multi-disciplinary research community that can provide comprehensive scientific support on air quality management to the decision makers in Vietnam, a collaborative scientific project has been established between the Vietnamese Academy of Science and Technology (VAST) and the International Institute for Applied Systems Analysis (IIASA). After the first year of the project, IIASA's Greenhouse gas –Air pollution Interactions and Synergies (GAINS) model, a scientific tool that is widely used across the world for the design of cost-effective pollution control strategies, has been adapted to the specific conditions of northern Vietnam, and implemented for the Greater Ha Noi/Red River Delta area and surrounding regions.

Many emission sources in Ha Noi and its surroundings contribute to PM2.5 in the city

It is found that, despite the large size of Ha Noi, only about one third of PM2.5 in ambient air originates from local emission sources (at traffic hot spots, the share can be higher).About two thirds third is imported from the Greater Ha Noi/Red River Delta region, while the remainder originates from other provinces in Vietnam, other countries, international shipping and natural sources.

In contrast to wide-spread believe, road traffic is not the dominating source of PM2.5 pollution in Ha Noi, although it contributes with about one quarter the largest share. About three quarters originate from other sectors. It is estimated that about 20% of PM2.5 in ambient air in the Ha Noi comes from large power plants and large industries, 15% is caused by emissions from the residential sector (cooking with biomass), another 15% from ammonia emissions from livestock farming and fertilizer application, and about 7% from the open burning of agricultural waste.

Despite the adopted policy measures, Ha Noi's air quality could further deteriorate in the future

The analysis suggests that the increased levels of economic activities following the anticipated economic growth path will counteract the air quality benefits of the ambitious pollution control measures that have been adopted by the authorities. In particular, it is estimated that without further policy measures, by 2030 PM2.5 concentrations in northern Vietnam could be 25-30% higher than in 2015 despite the recent regulations on emission standards. This would imply that almost 85% of the population in northern Vietnam will be exposed to air quality that does not conform with the national ambient air quality standard for PM2.5.

Effective improvements of Ha Noi's air quality require coordination with neighboring provinces

The analysis clearly indicates that even the most stringent emission control measures, if restricted to the Ha Noi area, will not be sufficient to effectively approach Vietnam's national ambient air quality standards. Even the most ambitious technical emission control measures, if implemented only in the Ha Noi, could reduce ambient levels of PM2.5 in 2030 by only 10%, down to 52 μg/m³ which is more than twice the national ambient air quality standard. Since in such a scenario about 85% of the pollution would be imported from outside the Ha Noi, coordinated action with neighboring provinces is indispensable for any effective improvements of air quality within Ha Noi.

Policy interventions could significantly improve air quality in northern Vietnam

Although further work is required before specific policy recommendations can be derived from the GAINS-Vietnam tool, the initial analysis clearly indicates that a host of policy interventions could deliver significant air quality improvements in the region, facilitate compliance with the national ambient air quality standards, and move closer to the global air quality guidelines of the World Health Organization. Cost-effective strategies need to combine technical emission controls such as effective cleaning of flue gas with policies that promote structural changes, e.g., energy efficiency improvements and transition to cleaner fuels. The GAINS-Vietnam tool, once fully implemented with local data and validated against observations, can help identifying effective portfolios of measures.

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