Global Environmental Change 53 (2018) 1–11

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Outlook for clean air in the context of sustainable development goals

Peter Rafaj[a,*], Gregor Kiesewetter[a], Timur Gül[b], Wolfgang Schöpp[a], Janusz Cofala[a], Zbigniew Klimont[a], Pallav Purohit[a], Chris Heyes[a], Markus Amann[a], Jens Borken-Kleefeld[a], Laura Cozzi[b]

[a] International Institute for Applied Systems Analysis (IIASA), Air Quality and Greenhouse Gases Program, Schlossplatz 1, 2361 Laxenburg, Austria
[b] International Energy Agency IEA/OECD, World Energy Outlook: Energy Demand Division, 31-35, rue de la Fédération, 75739 Paris Cedex 15, France

ARTICLE INFO

Keywords:
Sustainable development
Air quality policy
Energy access
Health impacts
Emission control

ABSTRACT

Air pollution is linked with many of the United Nations Sustainable Development Goals. Strategies aiming at the improved air quality interact directly with climate mitigation targets, access to clean energy services, waste management, and other aspects of socio-economic development. Continuation of current policies in the key emitting sectors implies that a number of sustainability goals will likely not be met within the next two decades: emissions of air pollutants would cause 40% more premature deaths from outdoor air pollution than today, carbon emissions would rise globally by 0.4% per year, while nearly two billion people would not have access to clean cooking. This paper examines integrated policies to put the world on track towards three interlinked goals of achieving universal energy access, limiting climate change and reducing air pollution. Scenario analysis suggests that these goals can be attained simultaneously with substantial benefits. By 2040, emissions of main pollutants are projected to drop by 60–80% relative to today, and associated health impacts are quantified at two million avoided deaths from ambient and household air pollution combined. In comparison to costs needed for the decarbonization of global economy, additional investments in air pollution control and access to clean fuels are very modest against major societal gains. However, holistic and systemic policy assessment is required to avoid potential trade-offs.

1. Introduction

Air pollution is the fourth greatest overall risk factor for human health worldwide, after high blood pressure, dietary risks and smoking. Recent estimates attribute 6.5 million premature deaths to air pollution (WHO, 2016). In addition to human health, air pollution poses risks to the environment, economy and food security. Air pollution crisis cannot be addressed in isolation: it is closely linked to policies for energy, climate, transport, trade, agriculture, biodiversity and other issues. Well-designed air quality strategies have major co-benefits for other policy goals (Anenberg et al., 2012; Rafaj et al., 2006; Schmale et al., 2014; Shindell et al., 2012). Improving air quality, via greater efficiency and increased deployment of renewables, goes hand-in-hand with the broader energy sector transformation and decarbonization commitments adopted within the Paris agreement (Mace, 2016; McCollum et al., 2013; Rafaj et al., 2013). Reducing pollutant emissions improves water and soil quality, crop yields and, in turn, food security (Emberson et al., 2001). Tackling household air pollution (HAP), via the provision of modern energy for cooking and lighting, helps development efforts dealing with poverty, education and gender equality (Amegah and Jaakkola, 2016; Lam et al., 2016; Rao and Pachauri, 2017).

In September 2015, 193 countries, developing and developed countries alike, adopted the Sustainable Development Goals (SDG), known officially as the 2030 Agenda for Sustainable Development (UN, 2015). Air pollution is recognized as a pressing sustainability concern and is directly mentioned in two SDG targets: SDG 3.9 (substantial reduction of health impacts from hazardous substances) and SDG 11.6 (reduction of adverse impacts of cities on people). Interlinkages of air pollution with other SDGs are described in detail in Supplementary material (Section S1). Action in the energy sector, including industry, transport and domestic subsectors, is essential to the attainment of the air pollution related SDGs (Amann et al., 2013; IEA, 2017). The majority of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions to the atmosphere are energy-related, as are some 85% of emissions of particulate matter (PM). Within the energy sector, power generation and industry are the main sources of SO_2. Oil-products use in vehicles and power generation are the leading emitters of NO_x. Consumption of

* Corresponding author.
E-mail address: rafaj@iiasa.ac.at (P. Rafaj).

https://doi.org/10.1016/j.gloenvcha.2018.08.008
Received 9 April 2018; Received in revised form 29 August 2018; Accepted 31 August 2018

biomass, kerosene and coal in the buildings sector, along with industrial combustion and process emissions, are responsible for the bulk of PM reaching the atmosphere. These three key pollutants are responsible for the most widespread impacts of air pollution, either directly or once transformed into other pollutants via chemical reactions and transport in the atmosphere. Fine particulate matter ($PM_{2.5}$) is the most damaging to human health, and sulfur and nitrogen oxides (a precursor of ozone) are associated with a range of illnesses and environmental damages (Cohen et al., 2017; Kiesewetter et al., 2015).

Each of the main pollutants is linked to a main fuel and source. In the case of $PM_{2.5}$, this is the wood and other solid biomass that some 2.7 billion people use for cooking and kerosene used for lighting (and in some countries also for cooking), which incurs indoor pollution that is associated with around 3.5 million premature deaths each year (Balakrishnan et al., 2013; Smith et al., 2014). These effects of energy poverty are felt mostly in developing countries in Asia and sub-Saharan Africa (Marais and Wiedinmyer, 2016). Fine particles, whether inhaled indoors or outdoors, are particularly harmful to health as they can penetrate deep into the lungs. Exposure to $PM_{2.5}$ may not be regarded as solely an urban problem (Zhang and Day, 2015); poor air quality severely affects many rural communities, moreover, significant share of secondary pollutants can be transported over large distances from their sources (Brauer et al., 2012; Klimont et al., 2017). The main fuel associated with sulfur emissions is coal (although high-sulfur oil products, such as those still permitted for use in maritime transport, are also a major contributor): SO_2 is a cause of respiratory illnesses and a precursor of acid rain. Fuels used for transport, first and foremost diesel, generate more than half the NO_x emitted globally, which can trigger respiratory problems and the formation of other hazardous particles and pollutants, including ozone. These emissions are linked with industrialization and urbanization, and coal and oil are the main sources (natural gas emits far less air pollution than other fossil fuels, or biomass). The unabated combustion of coal and oil in power plants, industrial facilities and vehicles is the main cause of the ambient/outdoor pollution linked to around 3 million premature deaths each year (IEA, 2016; Landrigan et al., 2017).

As the predominant source of air pollution and climate forcers, the fuel combustion must be at the forefront of action to improve air quality around the world. A range of proven policies and technologies are available to do so. In the United States, European Union and Japan, regulations have helped to achieve a major drop in emissions in some sectors, although challenges remain (Henneman et al., 2017; Rafaj et al., 2014; Wakamatsu et al., 2013). In developing Asia, less stringent regulations relating to fuel quality, energy efficiency and post-combustion treatment technologies generally mean that pollutant emissions have risen in line with very rapid growth in energy demand seen in recent years, though improvements in air quality are becoming an increasingly urgent policy priority in many Asian countries (Rafaj and Amann, 2018; Jin et al., 2016; Wang et al., 2014; Zhao et al., 2016). In other regions, particularly in Sub-Saharan Africa, urban air quality has been identified as a major threat to human health driven by rapid population growth and expanded transport and industry sectors, whereas lack of political will and institutional engagement poses major challenges to tackle impacts of air pollution (Amegah and Agyei-Mensah, 2017).

Since the SDG policy context has been introduced only recently, the scenario literature on the air-pollution-related SDGs interactions in medium/long-term is rather scarce and does not reflect yet, inter alia, the recent evolution in climate negotiations (see, e.g., Rao et al., 2016; van Vuuren et al., 2015; Roehrl, 2012). More recent studies, however, address implications of meeting the Paris agreement on a set of SDGs, including air pollution and health impacts (Grubler et al., 2018; McCollum et al., 2018), and suggest substantial co-benefits due to a rapid decarbonization of global economy and changes to consumption patterns. Evaluation of impacts – including potential tensions and trade-offs (Bowen et al., 2017; Klausbruckner et al., 2016) – of attaining multiple SDGs on the future air quality and associated health indicators requires an integrative and novel approach capable of quantifying interactions between key policy domains covered in this paper: access to clean energy carriers, climate change mitigation and abatement of air pollutant emissions. Using the policy scenario assessment, we attempt to contribute to this research area by quantifying and highlighting implications of multi-objective approach for sustainable development in contrast with a single-goal-oriented air pollution strategies.

Description of scenarios analyzed in this study together with key assumptions are provided in the next section; thereafter, the methodology and modelling tools are summarized. Subsequently, quantitative results are discussed in terms of future emissions of air pollutants, concentrations of fine particles, health impacts, and investment cost. Finally, conclusions and policy insights are drawn based on the numerical results.

2. Scenarios

This analysis is conducted on the basis of three scenarios: the New Policies Scenario (NPS), which assumes the continuation of existing and planned policies, the Clean Air Scenario (CAS), in which the implementation of additional measures achieves a significant reduction in air pollutant emissions, and the Sustainable Development Scenario (SDS), the aim of which is to address the three interlinked sustainability goals of achieving universal energy access, limiting climate change and reducing air pollution. Analysis of the NPS and SDS scenarios has been initially presented by the International Energy Agency's World Energy Outlook 2017 (IEA, 2017), and the first version of the CAS scenario has been reported in 2016 by the IEA's special report on energy and air pollution (IEA, 2016). For each scenario, underlying assumptions, policies and technological measures that determine emission levels from key sectors, are summarized in Table ST1 in the Supplementary material.

The New Policies Scenario (NPS) is the central scenario of this analysis, and aims to provide a sense of the direction in which latest policy ambitions could take the energy and industrial sectors. In addition to incorporating policies and measures that governments around the world have already put in place (Table ST1), it also takes into account the effects of announced energy, climate and air pollution policies, as expressed in official targets and plans. The Nationally Determined Contributions (NDC) of the Paris Agreement provide important additional guidance regarding energy policy intentions. Given that "new policies" are by definition not yet fully reflected in legislation or regulation, the prospects and timing for their full realization are based upon our assessment of the relevant political, regulatory, market, infrastructural and financial constraints.

The policies in place and under consideration to tackle air pollution vary considerably by country and region, with the state of economic development being an important variable. They encompass efforts that specifically target a reduction in pollutant emissions (e.g. setting upper limits for the concentration of individual pollutants in the flue gas stream). They also include broader policy efforts that change the pattern of energy consumption and thereby also have an impact on emissions trends (e.g. policies that support renewable energy or improve energy efficiency, or put a price on carbon).

The Clean Air Scenario (CAS) sets out a plausible strategy based on existing technologies and proven policies, to cut 2040 pollutant emissions by more than half compared with NPS. This policy path is one in which the energy sector takes determined action, coordinated effectively with others, to deliver a comprehensive overall improvement in air quality. Key areas for policy actions comprise a) setting an ambitious long-term air quality goal, to which all stakeholders can subscribe and against which the efficacy of the various pollution mitigation options can be assessed; b) putting in place a package of clean air policies for the energy sector to achieve the long-term goal, drawing on an efficient mix of best available practices, direct emissions controls, regulation and