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AIR POLLUTION SCENARIOS GENERATED BY SOLID WASTE MANAGEMENT: A CURRENT CHALLENGE IN THE DEPARTMENT OF BOYACÁ, COLOMBIA

ESCENARIOS DE CONTAMINACIÓN ATMOSFÉRICA GENERADOS POR LA GESTIÓN DE RESIDUOS SÓLIDOS: UN RETO ACTUAL EN EL DEPARTAMENTO DE BOYACÁ, COLOMBIA

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ABSTRACT

This work investigates several scenarios of waste management in the department of Boyacá, Colombia. Previous research have identified the potential risks of improper waste management, including the disposal of large amounts of organic matter increasing levels of CH_4, NO_x, SO_x, O_3, CO_2, black carbon (BC) and organic carbon (OC). Despite the relative short life span of these pollutants, changes in waste sector and final disposal policies causes a significant impact in urban air quality, ecosystems and health. In this way, this paper proposes a method that estimates short-lived climate pollutants from years 2000 to 2050, based in the collection of available data in the waste sector of Boyacá. The estimation models has been conducted using the SWEET 2.0 tool, an initiative from the Climate and Clean Air Coalition of the United Nations Environment Program. Each model includes a baseline and the analysis of three scenarios: (1) new compost facility; (2) landfill upgrades and (3) expand recycling. Results indicate that by 2050 levels of air pollution will continue to show a growing trend, so a detailed analysis of the current situation of waste management should be done. In the future, expanding recycling should be promoted in order to reduce the emissions of specific pollutants such as CO_2, CH_4 and black carbon in Boyacá.

KEYWORDS:

Air pollution; estimation models; waste management; short-lived climate pollutants; landfills.

RESUMEN

Este trabajo investiga varios escenarios de gestión de residuos en el departamento de Boyacá, Colombia. Investigaciones anteriores han identificado los riesgos potenciales de una gestión inadecuada de los residuos, incluyendo la disposición de grandes cantidades de materia orgánica que aumentan los niveles de CH_4, NO_x, SO_x, O_3, CO_2, carbono negro (CN) y carbono orgánico (CO). A pesar de la relativamente vida corta de estos contaminantes, cambios en el sector de los residuos sólidos y las políticas de disposición final generan un impacto significativo en la calidad del aire urbano, los ecosistemas y la salud. De esta forma, este trabajo propone un método de estimación de contaminantes climáticos de vida corta desde el año 2000 hasta el año 2050 basado en la recolección de datos disponibles en el sector de residuos de Boyacá. Los modelos de estimación se han realizado utilizando la herramienta SWEET 2.0, una iniciativa de la Coalición para el Clima y el Aire Limpio del Programa de las Naciones Unidas para el Medio Ambiente. Cada modelo incluye una línea base y el análisis de tres escenarios: (1) nueva instalación de compostaje; (2) mejora del vertedero y (3) ampliación del reciclaje. Los resultados indican que para el año 2050 los niveles de contaminación atmosférica seguirán mostrando una tendencia creciente, por lo que debería realizarse un análisis detallado de la situación actual de la gestión de residuos. En el futuro, se debe promover la ampliación del reciclaje para reducir las emisiones de contaminantes específicos como CO_2, CH_4 y carbono negro (CN) en Boyacá.

PALABRAS CLAVE

Contaminación atmosférica; modelos de estimación; gestión de residuos; contaminantes climáticos de vida corta; vertederos.

RESUMO

Este documento investiga vários cenários de gestão de resíduos no departamento de Boyacá, Colômbia. A investigação anterior identificou os riscos potenciais de uma gestão inadequada dos resíduos, incluindo a eliminação de grandes quantidades de matéria orgânica que aumentam os níveis de CH4, NOx, SOx, O3, CO2, carbono preto (NC) e carbono orgânico (OC). Apesar da vida relativamente curta destes poluentes, as mudanças no sector dos resíduos sólidos e nas políticas de eliminação têm um impacto significativo na qualidade do ar urbano, nos ecossistemas e na saúde. Assim, este documento propõe um método para estimar os poluentes climáticos de curta duração de 2000 a 2050 com base na recolha de dados disponíveis no sector dos resíduos de Boyacá. Os modelos de estimação foram feitos utilizando a ferramenta SWEET 2.0, uma iniciativa da Coligação Clima e Ar Limpo do Programa das Nações Unidas para o Ambiente. Cada modelo inclui uma linha de base e uma análise de três cenários: (1) nova instalação de compostagem; (2) melhoramento de aterros sanitários; e (3) expansão da reciclagem. Os resultados indicam que até ao ano 2050 os níveis de poluição atmosférica continuarão a mostrar uma tendência crescente, pelo que deverá ser efectuada uma análise detalhada da situação actual da gestão de resíduos. No futuro, a expansão da reciclagem deve ser promovida para reduzir as emissões de poluentes específicos, tais como CO2, CH4 e carbono preto (NC) em Boyacá.

PALAVRAS-CHAVE

Poluição atmosférica; modelos de estimativa; gestão de resíduos; poluentes climáticos de curta duração; aterros sanitários.

1. INTRODUCTION

Atmospheric pollution has become a problem that affects today's civilization demanding immediate global solutions (Lezama, 1996; Quijano B., Díez Silva, Montes Guerra & Castro Silva, 2014). Despite the countless efforts of international and governmental entities to control the deterioration of the environment, with the passage of time, particulate matter emissions are reaching levels that imply considerable damage to human health. According to a study by the World Health Organization (WHO), air pollution is the fourth leading risk factor for premature deaths; exposure to a polluted atmosphere causes one out of every ten deaths worldwide. This situation mainly affects low-income populations living in developing countries (Medina, 2019).

In Colombia, poor air quality is associated as one of the main environmental risk factors affecting public health. According to the National Institute of Health (INS), each year about 17549 deaths are caused by exposure to a polluted atmosphere (Qian et al., 2021) a figure that represents about 8% of the total number of deaths nationwide. The mortality of people of productive age is affecting the economy by causing costs amounting to $545000 COP, equivalent to 0.068% of the country's Gross Domestic Product (GDP). This panorama is considerably amplified when taking into account population growth, industrialization and individual and social behaviours, which distort demographics in the territories and limit their capacity to comply with hygiene and basic sanitation services designed to cover less dense population centers. Inadequate hygiene and integral cleaning of cities, generates soil, air and water pollution, negative visual impacts, odors and leachates, deteriorating the quality of life of its inhabitants and favoring the spread of other diseases (Lezama, 1996).

According to previous studies (García-Ubaque, García-Ubaque & Vaca-Bohórquez, 2021; Eriksson et al., 2005; Roa et al., 2019), the inadequate management of solid waste in cities is a triggering factor of atmospheric pollution by releasing a wide variety of particles and gases, which are the result of the damming of significant amounts of organic matter and other decomposing waste. Among the gases released are short-lived climate pollutants (SLCPs), especially methane (CH_4), black carbon (BC) and tropospheric ozone (O_3), as well as greenhouse gases, such as carbon dioxide (CO_2). Inappropriate solid waste management also facilitates the growth of bacteria, viruses, fungi and parasites that can reach the population through direct contact or through insects or domestic animals (Bond, 2013).

1.1 Solid waste management and landfill technology

Currently, urban solid waste management is carried out through three stages: collection, transportation, and final disposal, as shown in Figure 1. Each stage comprises a series of activities executed by the providers of domiciliary public services of each municipality. According to the Superintendency of Residential Public

Utilities (SSPD for its acronyms in Spanish) for the year 2018 about 961 municipalities of the 32 departments generated approximately 30973 tons of waste per day (see Table 1) (Disposición Final de Residuos Sólidos-informe nacional 2018, 2019), which were placed in the different final disposal systems. Of the total, about 96.01 % were placed in sanitary landfills, 1.98 % in open dumps, 1.69 % in contingency cells, 0.22 % in transitory cells and 0.1 % in treatment plants (Agudelo-Calderón, 2015); thus, landfills are defined as the predominant site for the final disposal of urban solid waste.

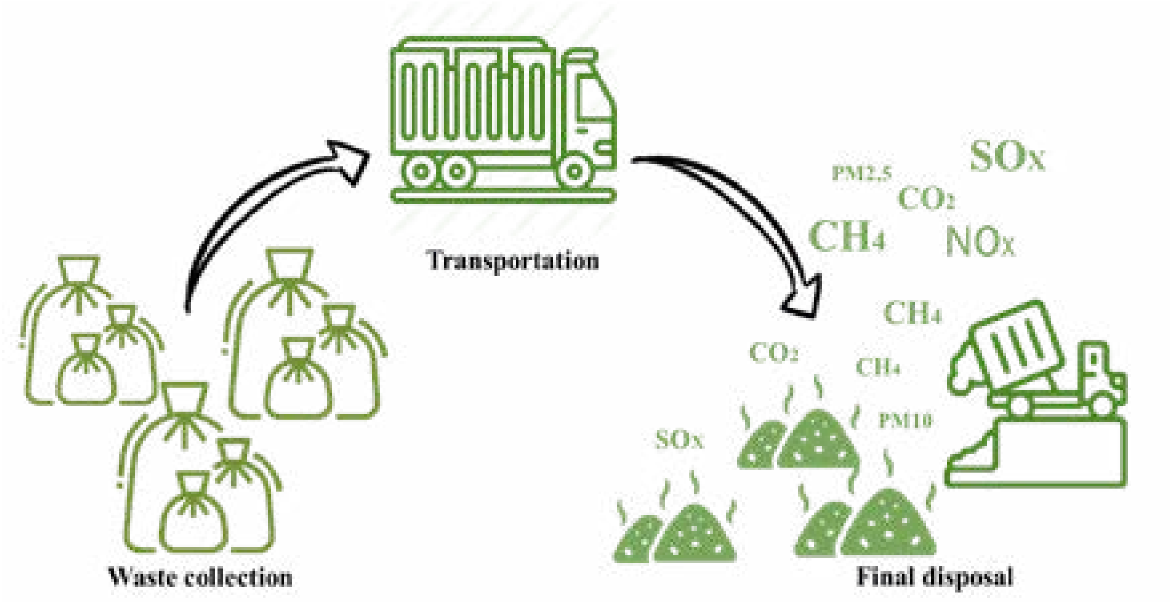

Figure 1. Current stages of solid waste management in Colombia: waste collection, transportation and final disposal.

In Boyacá's department, 119 of the 123 municipalities have authorized disposal of urban solid waste, in which the production of 483.66 tons/day of urban solid waste is concentrated, whose final disposal is distributed in four sanitary landfills: Parque Ambiental Pirgua (360.54 tons/day) located in the municipality of Tunja, Terrazas del Porvenir (78.54 tons/day) located in Sogamoso, Carapacho (34.13 tons/day) in Chiquinquirá and the Regional Solid Waste Plant (10.45 tons/day) located in the municipality of Garagoa (Agudelo-Clderón, 2015).

Table 1. Current generation of solid waste by department according to DANE Census of 2018 (DANE, 2018).

Department	Population (DANE Census, 2018)	Current waste generation (Ton/day)	Department	Population (DANE Census, 2018)	Current waste generation (Ton/day)
Vaupés	3.70	40797	Nariño	1630592	606.00
Amazonas	8.42	76589	Meta	1039722	606.72
Guainía	11.84	48114	Caldas	998255	624.36
Vichada	24.12	107808	Risaralda	943401	685.74
Guaviare	42.01	82767	Córdoba	1784783	738.71
Archipelago of San Andrés	83.60	61280	Cesar	1200574	759.65
Putumayo	132.59	348182	Tolima	1330187	798.60
Arauca	152.29	262174	Magdalena	1341746	815.47
Chocó	162.53	534826	Norte de Santander	1491689	1023.84
Caquetá	193.08	401849	Santander	2184837	1377.27
Casanare	235.04	420504	Cundinamarca	2919060	1591.13
Quindío	354.78	539904	Bolivar	2070110	1827.40
La Guajira	365.90	880560	Atlántico	2535517	2387.50
Sucre	391.32	904863	Antioquia	6407102	3575.26
Cauca	405.60	1464488	Valle del Cauca	4475886	3592.68
Boyacá	483.66	1217376	Bogotá, D.C.	7412566	6366.24
Huila	545.90	1100386			

In this way, the main objective of this work is to estimate the emissions of SLCPs and other greenhouse gases generated by the final disposal of solid waste in the department of Boyacá. The estimation uses population data, statistics on waste generation in rural and urban areas, composition of urban solid waste, quantity and types of final disposal systems, means of transportation, among others. This information complements the estimation model, which is run using the SWEET 2.0 tool, an initiative of the Climate and Clean Air Coalition of the United Nations Environment Program (UNEP). The results are compared with possible management scenarios, so that stakeholders can make decisions based on final disposal measures that involve the least amount of emissions to the atmosphere. In this way, air quality management will be boosted and the formulation of prevention and control policies coordinated with the different actors of the system will be promoted, focusing their efforts on those activities considered turning points in the generation of SLCPs in the department.

2. METHODOLOGY

To assess an emission baseline of SLCPs from years 2000 to 2050 we used the Solid Waste Estimation Tool (SWEET) version 2.1, an initiative developed by Abt Associates and SCS Engineers as a part of the Climate and Clean Air Coalition Municipal Solid Waste Initiative and the

U.S. Environmental Protection Agency (Gaitán & Cárdenas, 2017). The tool assists users estimating annual emissions of methane (CH_4), black carbon, nitrogen oxide (NOx), sulphur oxide (SOx) and other pollutants such as carbon dioxide (CO_2). We collected detailed information from governmental reports and developed three possible scenarios for waste management. The sources for the estimation include:

Population statistics inside and outside of formal collection zones based on National Administrative Department of Statistics (DANE, 2018).

Waste generation, collection rates and transportation data from the national solid waste disposal report issued by the Superintendency of Domiciliary Public Utilities in 2019 (Bond, 2013).

Detailed information of landfills and dumpsites, waste combustion equipment and waste burning data from the Single Public Utilities Information System (SUI, for its acronym in Spanish) (Suárez & Romero, 2018).

Waste handling equipment of landfills based on the management reports carried out by the Superintendency of Residential Public Utilities to the companies that provide residential public utilities (Salinas, 2017).

Information of composting facilities available inside Boyacá's department.

To calculate the average of annual precipitation (mm/year) and annual temperature, we reviewed data from 10 years registered in the weather and climate database reported by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) (Suárez, Sepúlveda, Patarroyo & Canaria, 2020).

Per capita waste generation rates at collection zones are given by Equation (1) where W_{GR} is the waste generation rate inside or outside formal collection zones, W_{day} is the amount of waste in kg generated by population during the last year and P_{CZ} is the population inside or outside formal collection zones.

$$W_{GR}=W_{A}\frac{1}{P_{CZ}*365}\left(\frac{kg}{capita*day}\right) \quad (1)$$

An important aspect of our analysis is related to the emissions from different types of vehicles used for waste handling. This information includes equipment to handle waste at landfills and dumpsites, composting facilities and other scenarios involved in waste management as showed in Table 2.

Table 2. Emission factors of traditional fuels (Khan et al., 2019; Demirgok, 2021)

Type of vehicle	Operating status	Emission factors							
		Black carbon	Organic carbon	Methane	Carbon dioxide	NOx	SOx	PM2.5	PM10
Heavy-duty trucks using gasoline	In-use (g/km)	0.001	0.012	0.029	889	2.609	0.052	0.074	0.090
	Idling (g/hour)	0.014	0.085	–	8.350	5.330	0.029	–	–
Heavy-duty trucks using diesel fuel	In-use (g/km)	0.807	0.260	0.004	889	4.642	0.087	0.285	0.309
	Idling (g/hour)	4.660	1.498	–	5.700	30.343	0.029	1.103	1.199
Light-duty trucks using gasoline	In-use (g/km)	0.003	0.017	0.055	301	1.699	0.014	0.069	0.079
	Idling (g/hour)	0.014	0.085	–	8.350	4.065	0.014	–	–
Light-duty trucks using diesel fuel	In-use (g/km)	0.241	0.100	0.004	301	1.919	0.027	0.146	0.159
	Idling (g/hour)	4.660	1.498	–	10.100	3.705	0.027	1.093	1.188

To estimate the SLCPs for the scenarios 'new compost facility' and 'expand recycling' we used the characterization of waste collected at 'Terrazas del Porvenir' landfill, projected by 2017 (Coservicios S.A. E.S.P, 2018) and listed in Table 3. It is important to note that food waste, paper/cardboard, textiles and plastic are the main solid waste products. However, hygienic waste and related products were placed in the 'other' category and comprised about 17% of the total.

Table 3. Average composition of collected waste.

Waste type	Metric Tons	Percent
Food waste	45.017	25.5%
Green	2.648	1.5%
Wood	3.531	2.0%
Paper/Cardboard	31.776	18.0%
Textiles	17.654	10.0%
Plastic	34.954	19.8%
Metal	3.531	2.0%
Glass	5.120	2.9%
Tires	1.236	0.7%
Other	31.070	17.6%
Total	176.536	100 %

3. RESULTS AND DISCUSSION

Based on the data sources used in our model, we estimate that 1490394.12 metric tons of SLCPs will be released by 2050 as shown in figure 2. Similar behavior displayed the landfill upgrades scenario, in which could be released 1483476.13 metric tons, a new compost facility has a lower impact projecting the release of 1371481.03 metric tons by the same year. On the other hand, the scenario of expand recycling project that, in 2050, emissions could reduce to 28457.77 metric tons (approximately a reduction of 98.09 % from baseline). This reduction implies that total emissions could be significantly reduced by expanding recycling activities of urban solid waste by 2050.

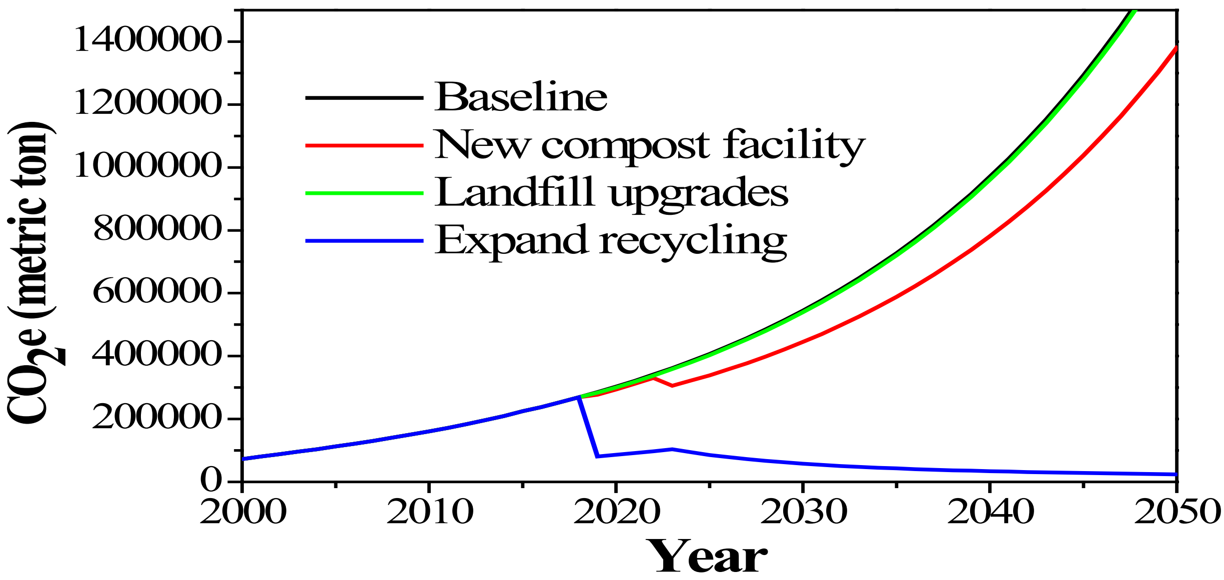

Figure 2. Total emissions in metric tons by scenario including SOx, NOx, CH_4, CO_2, organic carbon and black carbon from 2000 to 2050.

We identified independently each SLCPs in Figure 3 to quantify the amount of emissions in each scenario. We observe that only the scenario of expand recycling presented a decreasing behavior in all the estimation models. Although, a new compost facility displayed a decrease in methane emissions as depicted in figure 3b. Quantitatively, we observe that CH_4 in figure 3b, BC in Figure 3e and CO_2 in Figure 3f, are grouped as the main contributions of the total emissions above-listed. Individually, by 2050, emissions of CH_4 reach up to 578886.17 metric tons, BC emissions reach 410376.38 metric tons and CO_2 emissions up to 1498164.01 metric tons. A comparison between these results and known atmospheric projected values, showed that these models probed a well representation of global pollution budget previously reported (Haro et al., 2019; Vitolo, Scutari, Ghalaieny, Tucker & Russell, 2018; Fuglestvedt et al., 2010; Frey & Kuo, 2009).

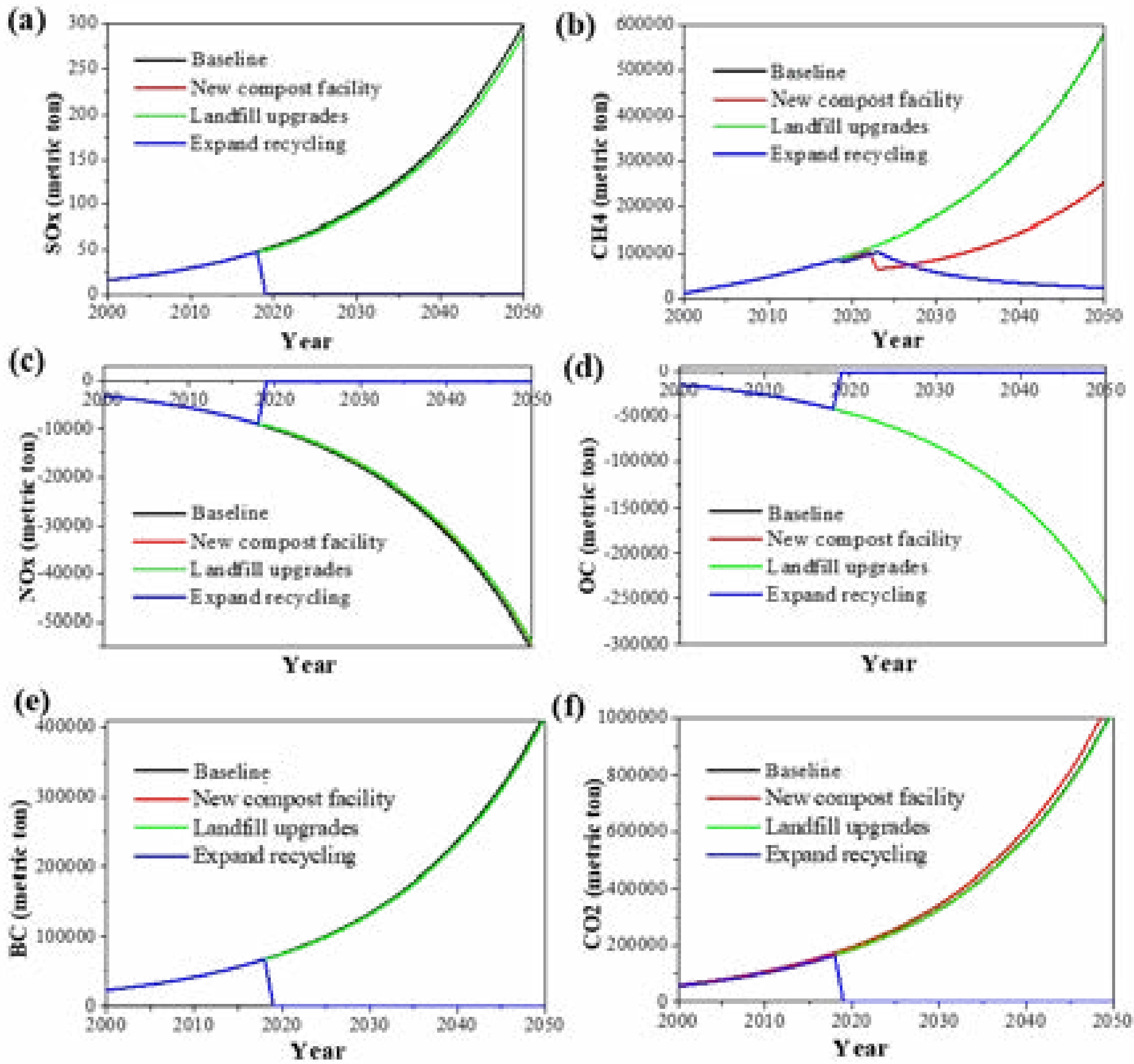

Figure 3. Scenario comparison of SLCPs emissions in metric tons over time. (a) SOx (b) CH_4 (c) NOx (d) OC (e) BC (f) CO_2.

The large contribution of CO_2 to the total emissions results from the amount of waste deposited in landfills and its chemical composition. Approximately, 17 % of total collected waste diverted from landfill to recycling could change significantly the CO_2 emissions. Therefore, the variation observed in expand recycling scenario is due to the reduction of wastes such as paper/ cardboard, textiles and plastic in the landfill with respect to the baseline scenario. Similarly, the outcome of the predicted model could be influenced as well by weather variables such as: mean annual precipitation and mean annual temperature of the region. This is logical as the weather variables exhibit several variations in pollution generation (Stockwell et al., 2014).

4. CONCLUSION

Based in the estimation models by 2050 emissions of SLCPs will continue to show an upward trend. In the future, activities such as expanding recycling of wastes will reduce significantly the emissions of contaminants to the atmosphere, especially CO_2, CH_4 and black carbon. This results provide stakeholders the ability of compare the benefits of emission reductions in each scenario for decision making of waste management projects. Finally, the present work aim to provide relevant information and to assist future studies that reduce the limitations in the pollutants estimation field.

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