Science of the Total Environment 537 (2015) 352–359

Contents lists available at ScienceDirect

Science of the Total Environment

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

Sensitivity analysis of biodiesel blends on Benzo[a]pyrene and main emissions using MOVES: A case study in Temuco, Chile

Ernesto Pino-Cortés [a,*], Luis A. Díaz-Robles [a], Francisco Cubillos [a], Joshua S. Fu [b], Alberto Vergara-Fernández [c]

[a] Departamento de Ingeniería Química, Universidad de Santiago de Chile, Chile
[b] Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, TN, USA
[c] Facultad de Ingeniería y Ciencias Aplicadas, Universidad de los Andes, Chile

ARTICLE INFO

Article history:
Received 7 April 2015
Received in revised form 2 July 2015
Accepted 28 July 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
MOVES
Mobile sources
Biodiesel
Temuco
Benzo[a]pyrene

ABSTRACT

Temuco is one of the most highly wood-smoke polluted cities in Chile; however, the diesel mobile sources are growing very fast in the past 10 years and so far very few studies have been done. The main goal of this research was to develop a 2013 emission inventory of criteria pollutants and Benzo[a]pyrene (BaP) and to evaluate the use of six biodiesel blends of 0%, 1%, 4%, 8%, 12%, and 20% by volume of fuel in diesel motors from the vehicle fleet within the mentioned areas using the Motor Vehicle Emission Simulator (MOVES). Input parameters for the base year 2005 were estimated to implement and adapt the model in Chile, while results of NOx, PM_{10}, $PM_{2.5}$, NH_3, CO_2 equivalent and SO_2 were compared with the Chilean Emission Inventory estimated by the model "Methodology for the Calculation of Vehicle Emissions." The 2013 emissions reduced with respect to 2005, in the majority of the contaminants analyzed, despite the 47% increase in the annual miles traveled. Using biodiesel blends, an emission reduction was estimated at up to 15% in particulate matter, BaP, and CO for the year 2013, as well as an increment of 2% in NOx emissions, attributed to low sulfur content (50 ppm) in the diesel and the antiquity of the vehicle fleet. The results obtained gave evidence of the influence of the biodiesel use in the pollutant emissions to improve the Chilean air quality, as well as providing a strategy for this air quality management.

1. Introduction

Currently, atmospheric pollution represents a serious problem for the health and the population lifespan (Romero-Lankao et al., 2013). Respiratory illnesses, cardiac, and cerebrovascular problems are some of the risks exposed to the populations of urban areas, such as in Santiago, Chile (Leiva et al., 2013; Díaz-Robles et al., 2014; Garcia-Chevesich et al., 2014). Economic development has generated an accelerated increment in industrialization and human activity, being considered one of the most polluted cities on a global level in the 80s (Escobedo et al., 2008). Among fundamental sources of emissions that still affect this city are industry, mobile sources, and the residential wood combustion. Since the year 1998, regulations and guidelines have been put into place to manage, control, and diminish the emissions from these sources, with the objective of establishing tools for air quality management and decision making.

However, Santiago is not the only city in Chile that still presents air quality problems. Several cities in the south of Chile have presented worse air pollution problems than Santiago, leading Temuco city and reaching the level of being considered non-attainment area for PM_{10} for almost 10 years (Faiz et al., 1996; Díaz-Robles et al., 2008a; Sanhueza et al., 2009; Nicolas Schiappacasse Poyanco et al., 2013; Díaz-Robles et al., 2014) and since 2012 for $PM_{2.5}$. The largest contribution of pollutants is due to the use of firewood as a fuel source in domestic heating, creating massive amounts of soot and air toxins. However, mobile sources have increased dramatically in the past 10 years in the city, and this new vehicle fleet contributes a series of pollutants that may cause harmful health effects in humans. These compounds are principally air toxics and diesel ultrafine particles (Díaz-Robles et al., 2008b; Sanhueza et al., 2009).

Diverse studies on emissions and modeling of air quality have been done in this urban zone, with the objective of stimulating the decision making process in policy. One of these sites corresponds to that done by DICTUC from the Universidad Católica de Chile. In this study, among other themes, an inventory was carried out for the year 2005 from mobile sources for the Temuco and Padre Las Casas counties, using the Chilean model MODEM II (CONAMA, 2008). The results indicated that the particulate matter (PM) emissions came fundamentally from vehicles that use diesel fuel, such as buses and trucks. Fortunately, the Chilean government has improved the quality of fuels since 2005 especially in the diesel sulfur content, as well as, better strategies for air quality management.

The use of emission inventory is one of the best tools for policy decision making in the air quality management and air pollution control. Currently there exist diverse models that permit the estimation of

* Corresponding author.
E-mail address: ernesto.pinoc@usach.cl (E. Pino-Cortés).

http://dx.doi.org/10.1016/j.scitotenv.2015.07.143
0048-9697/

emission from different pollution sources, especially from mobile sources (Díaz-Robles et al., 2008b, 2009; Díaz-Robles, 2013). As mentioned above, in the city of Temuco, the program MODEM II has been used to obtain results from these mobile sources (CONAMA, 2009). However, this emission model is limited so far, given that it can only analyze some pollutants, such as PM, carbon monoxide CO, total hydrocarbons (TH), nitrogen oxides (NOx), nitrous oxides (NO), sulfur dioxides (SO_2), methane (CH_4), ammonia (NH_3), and carbon dioxide (CO_2), leaving out the toxic contaminants in the analysis. Information about aged vehicle fleet and the content of the fuels used is not observed as well. Finally, MODEM II is not open-access software, restricting the state-of-the-art, further research, and improvement on the program. Fortunately, the Chilean government is trying to improve this software, for air quality management.

One of the best simulation programs with the largest state-of-the-art options for doing mobile sources inventory is the program MOVES implemented by the Office of Transportation and Air Quality in the United States, pertaining to the U.S. Environmental Protection Agency (Giannelli et al., 2005; Gurjar et al., 2010; Guldner, 2013). This model is capable of estimating emissions for the aforementioned pollutants, as well as an ample range of substances in multiple scales of analysis, permitting as well the free use of the software (EPA, 2012a, 2012b). The program in its version named 2010b, presents improvements in the database and error correction, permitting the emission estimations for metals, polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, and hydrocarbon gases, among others (EPA, 2012a, 2012b). MOVES presents a large and a robust database, as a result of millions of seconds of data and research by the EPA. For this reason, it is capable of estimating emissions from exhaust pipes, by evaporation (evaporative), as well as brake and tire wear of all types of vehicles on the road (EPA, 2012a, 2012b).

This model can also obtain results for areas outside of the United States, and this requires an advanced compilation of data. For this reason, it is recommended to employ the database that the program possesses that contains information about emission in the United States, as well as driving patterns, vehicle classes, and road types, among others (Koupal et al., 2010) but this requires calibration of the model to local conditions. The fuels that can be analyzed are gasoline, gas–ethanol mix, diesel, diesel–biodiesel blends, and CNG and liquefied natural gas (Gurjar et al., 2010; EPA, 2012a, 2012b). These data are similar to the conditions in Chile, where emission standards for highway vehicles, light-duty and heavy-duty, have been in place since the early 1990s. Dual standards often exist, allowing new engines to meet either US or EU standards.

Variables such as the sulfur content and the volatility of the fuels, meteorological data, vehicle fleet composition, annual miles traveled by vehicles, as well as the distribution of many types of freeways can be implemented and adapted for other regions outside the United States. Additionally, some variables can be employed such as vehicle maintenance and inspection, which is present by default in the database that is part of the program. This database was considered similar and valid for the areas of interest in Chile, given the high confidence that these values present the great complexity of study (Koupal et al., 2010).

2. Scope of the study

One of the advantages that MOVES offers is that it can simulate the emission of Benzo[a]pyrene (BaP), categorized as carcinogenic for the population (Nielsen et al., 1996). In fact, the Agency for Toxic Substances and Disease Registry has considered the BaP as the 8th in the Priority List of Hazardous Substances for 2013 (ATSDR, 2013), and it has been recently ratified by the US Environmental Protection Agency (EPA) as cancerogenic for humans, as well as by the World Health Organization (WHO), which has established an air quality regulation with an annual maximum average on BaP of 1 ng/m^3 for Europe. This air toxic compound is found in the exhaust of wood stoves and mobile sources (Nussbaumer and Hasler, 1999; Tsapakis et al., 2002; Nussbaumer, 2003; Lewtas, 2007; Bari et al., 2011). In the case of Chile, a monitoring and receptor model study found higher levels of polycyclic aromatic hydrocarbons (PAHs) and other airborne toxins in Temuco than Santiago (Tsapakis et al., 2002), where the BaP concentration in Temuco was 98.5 ng/m3 versus 10.9 ng/m3 in Santiago. The total PAH concentrations were 751 and 129 ng/m3 in Temuco and Santiago, respectively. Other study found lower concentrations of BaP at Temuco than the previous one during high $PM_{2.5}$ episodes in August 2008 (Cereceda-Balic et al., 2012; Pozo et al., 2015). They found a total gas and solid phase BaP concentration of 10.78 ng/m^3, which was sampled at the official Air Quality Monitoring Station of Temuco (Las Encinas), while Tsapakis et al. (2002) took the sample near emission sources. These high PAH concentrations have also been found in Christchurch, New Zealand, where some studies have analyzed urinary 1-hydroxypyrene in nonsmoking male schoolchildren, a biomarker for studying PAH exposure in humans (Cavanagh et al., 2007).

So far, the BaP has not been studied in mobile sources in Chile and considering the serious problem before, it is necessary to use MOVES's model to estimate and design control strategies for these emission sources. One of the strategies studied to reduce emissions by the exhaust pipe is the use of biodiesel in diesel motors. This biofuel is produced from vegetable oils and animal fats, resulting in a fuel with characteristics very similar to conventional diesel, making it possible to mix certain proportions of biofuel with the diesel with the objective of reducing emissions (Dwivedi et al., 2011). Chilean legislation allows up to 5% by-volume mix in diesel motors (Ministerio de Economía, 2008). However, the composition of biodiesel can be greater (Surawski et al., 2011).

In the last years, different studies have been done (Tsai et al., 2010; Karavalakis et al., 2011; Koc and Abdullah, 2013; Kumar et al., 2013; Paredes et al., 2013) in order to analyze the effect of mixing biofuels. The pollutants analyzed are centered around NOx, total hydrocarbons, CO, and particulate matter. Studies from the EPA (EPA, 2002) in the year 2002 show levels of reduction of up to 50%, in the latter two pollutants, using pure biodiesel, compared with the average emissions of conventional diesel, with a high sulfur content of 333 ppm. MOVES was designed to modify emissions when biodiesel is used in substitution of diesel.

Recently, average NOx emissions were found to increase by 2.2%, while PM, HC, and CO were found to decrease by 15.6%, 14.1%, and 13.8%, respectively, running on 20 vol.% biodiesel fuel on vehicle engines (Acevedo et al., 2011). Those factors were based on EPA analysis for RFS2 (Acevedo et al., 2010).

Emissions of NOx are generally increased upon increasing the percentage of biodiesel in the blend, although its behavior varies according to the cetane number and the origin of the biofuel used (McCormick et al., 2001; EPA, 2002; Karavalakis et al., 2009). Factors such as these, as well as other properties of the fuels, such as density, viscosity, degree of unsaturation, and operating conditions influence in its formation.

This study had the objective of evaluating the use of biodiesel in different blends in diesel motors for the vehicle fleet of the Temuco and Padre Las Casas counties, using MOVES. This was done to analyze the impact on emissions caused by mobile sources, especially focused on BaP, particulate matter, NOx, and CO. A model was also investigated to obtain new inventory of mobile source emissions in Chile which would provide an air quality management tool, useful in this country and as a model for other developing countries facing the same pollution issues.

3. Methodology

Temuco and Padre las Casas counties were considered as one region, dividing themselves in five zones, as is demonstrated in Fig. 1. This was done with the goal of assigning distribution factors to the freeways and of vehicle use that is closer to the real conditions. The required parameters from each one of these zones was fixed by estimations according to

Fig. 1. Zones of study in Temuco and Padre Las Casas counties.

the geographical characteristics as well as the economic conditions of the area, given that there did not exist prior information on the topic. Factors were established according to the types of roads presented in MOVES.

As an information source, the National Institute of Statistics (INE) of the Araucanía Region was utilized, the National Petroleum Company (ENAP in Spanish), as well as studies from the DICTUC. Furthermore, a database was used from the program on some variables, mentioned later in this article. This is because there do not exist current studies in Chile that permit a justified modification of these data.

In order to carry out an inventory outside of the United States, the MOVES requires 13 input variables, such as meteorological data, vehicle population, study area, and the characteristics of its freeways, the distribution of speed limits according to vehicle class and hour, the fraction of ramps or inclinations on the freeways, the distribution of the use of fuels, vehicle age distribution, the formula of the fuel, distribution of the miles traveled by the vehicles according to the type of route, maintenance and inspection programs carried out on the vehicles, the type of fuel and the technology according to the vehicle class, as well as the miles traveled per month, day and hour.

Emission simulations were carried out in time frames of one month, creating 12 work scenarios that were later added to obtain the base annual inventory from the year 2005. Once the input variables were accepted comparing the MOVES results with the Chilean emission inventory for 2005, the mobile sources inventory was then developed for the year 2013, replacing fuels with blends of biodiesel and diesel in vehicles that used diesel. These blends by volume of fuel were 0%, 1%, 4%, 8%, 12%, and 20%.

The vehicle classes present in MOVES were organized according to the patterns of vehicle activity (Koupal et al., 2010; EPA, 2012a, 2012b). It was part of the calibration done that there was a comparison done with the Chilean vehicle classes, establishing a consensus of the types of vehicles to use for the simulation. This classification is shown in Table 1 with their respective codes. Important to note is that they do not include ambulances, garbage trucks or mobile homes, for the lack of information regarding the miles traveled, number of units, pollution emission, and other key data.

In the Temuco and Padre Las Casas counties there exist urban as well as rural routes and MOVES presents 5 large types of routes for studying, which all were selected, as these are shown in Table 2. The classification of each one is given due to the characteristics that they present in the U.S., and for that reason an adaptation to the local communities was carried out. The distribution in the areas was estimated according to the geographic and economic characteristics, given the lack of real values regarding this topic.

Additionally, the types of roads presented subclassifications according to vehicular activity, geographic characteristics of the area, as well as the access to them (FHWA, 2013). MOVES requires the distribution of these subcategories on the highways and on the established areas. In Table 3 the parameters shown correspond to the subclassification of the roads in the simulation zones. It is important to note that the Rural Interstate category corresponds to the Route-5 South, being present only in the areas I and V. These values, corresponding to the fraction of roads by routes and zones of Temuco and Padre Las Casas counties, were estimated according to the geographic and economic characteristics of the zones, and should be improved in future studies, given the relevancy of the obtained results. The distinct types of routes present diverse emission factors, fundamentally explained by driving behavior (Koupal et al., 2010), for which it would be helpful to have information on factors that were as close to real as possible, obtaining better results and with that a more precise approach to decision making regarding the use of these biofuels.

The age of vehicle fleet is one of the input variables that affects emission factor and final results (Clark et al., 2002; Aguilera et al., 2009). With information published by INE (INE, 2013), the number of vehicles was estimated for the years 2005 and 2013. This was done using the circulation register of each vehicle class from 1990 to 2011. An extrapolation was also realized in the periods from 1985 to 1989 and from 2012 to 2013.

MOVES allows the introduction of antiquity distributions up to 30 years, but due to the lack of real data, vehicles with a maximum age

Table 1
Vehicle classes considered for the simulations.

ID	MOVES vehicular class	INE vehicular class
11	Motorcycle	Motorcycle
21	Passenger car	Personal vehicles (sedan, station wagon)
31	Passenger truck	Jeeps, pick-ups, vans (include basic and shared taxis)
32	Light commercial truck	Commercial small trucks
42	Transit bus	Buses
52	Single unit short-haul truck	Light trucks
53	Single unit long-haul truck	Medium trucks
62	Combination long-haul truck	Heavy trucks

Table 2
Types of roads present in MOVES.

ID road	Name	Characteristics
1	Off-network	All of the zones where vehicle activities that predominate are parking and starting places, idling places such as truck stops, bus terminals, rest areas, etc.
2	Rural restricted access	Rural highways that can only be accessed by an on-ramp
3	Rural unrestricted access	Other types of rural roads considered arterials, connectors and local streets.
4	Urban restricted access	High speed urban routes only accessible by a ramp.
5	Urban unrestricted access	Other types of urban roads considered arterials, connectors and local streets.

Table 3
Distribution of fraction of roads by routes and zones of Temuco and Padre Las Casas counties.

ID Route	Name	Zone I	II	III	IV	V
2	Rural interstate	1.0	0.0	0.0	0.0	1.0
3	Rural principal arterial	0.0	0.0	0.0	0.0	0.0
3	Rural minor arterial	0.4	0.2	0.4	0.2	0.4
3	Rural major collector	0.0	0.0	0.0	0.0	0.0
3	Rural minor collector	0.3	0.3	0.3	0.3	0.3
3	Rural local	0.3	0.5	0.3	0.5	0.3
4	Urban interstate	0.0	0.0	0.0	0.0	0.0
4	Urban freeway/expressway	1.0	1.0	1.0	1.0	1.0
5	Urban principal arterial	0.0	0.0	0.0	0.0	0.0
5	Urban minor arterial	0.2	0.3	0.2	0.3	0.3
5	Urban collector	0.5	0.4	0.5	0.4	0.4
5	Urban local	0.3	0.3	0.3	0.3	0.3

of 20 years were used for the year 2005 and 28 years for 2013. In Tables 4 and 5, the age ranges of the vehicle pool are shown for the inventories corresponding to the years 2005 and 2013, respectively.

The age that the Chilean vehicle pool presents is older than that of the database of MOVES, and for that reason the default database was not employed for this study, and it is of significant effect on emissions by mobile sources. Various studies have concluded that improvements in technology appearing in newer vehicles cause them to present lower emission values (Symeonidis et al., 2003; Dohanich et al., 2004). According to Nigel (Clark et al., 2002), there exists two factors of vehicle age that affect the emissions by mobile sources. One of these is the deterioration of the motors over time, assuming that they accumulate miles. The other factor is the change in technology that implies that motors produced currently are fabricated under stricter emission controls, marking the difference between older models.

In contrast, the vehicle population was established for the year 2005, data that was obtained from publications by INE (INE, 2013). It is important to highlight that the number of trucks was established on the base of the miles traveled by this vehicle class shown in the study by DICTUC, in this way creating a relationship between them. The same vehicle fleet was used in 2005; however, the annual miles traveled (AMT) increment was about 47% from 2005 to 2013, in average. In Tables 4 and 5 values can be seen for the years 2005 and 2013, respectively, showing also the AMT for each vehicle class. For the year 2005, these values were extracted and established according to the tendencies of growth for the vehicle pool existing during the period 2009 to 2011, according to information given by the INE (INE, 2013). The distribution of the fuels used by the vehicle classes is shown in Table 6.

Another factor that has a direct impact on the results is the monthly distribution of the miles traveled by the vehicles. These were estimated according to the season of the year in the southern hemisphere, being the months of summer (December to March) and winter (June to September) of higher and lower proportion, respectively. Because of the nonexistence of studies regarding this topic in this study area, the present default values in the MOVES database were used, switched to seasons in the southern hemisphere. The resulting distribution is shown in Table 7.

Table 4
Miles traveled, vehicle age, and population from the year 2005.

ID	Vehicle pool	AMT	Age of vehicle in years (%)			
			0–5	6–10	11–15	>15
11	463	1 316 326	34.99	22.25	42.76	0.00
21	25 735	137 733 523	26.33	23.64	36.50	13.54
31	2 100	109 988 297	22.33	32.24	20.86	24.57
32	15 886		19.68	25.70	35.58	19.04
42	1 076	24 910 803	77.97	6.78	15.24	0.00
52	997	8 658 496	24.07	11.58	32.54	31.81
53	1 016		24.07	11.58	32.54	31.81
62	172	74 104	24.07	11.58	32.54	31.81

Note: AMT annual miles traveled.

Table 5
Miles traveled and vehicle age from the year 2013.

ID	AMT	Age of vehicle in years (%)			
		0–5	6–10	11–15	>15
11	6 226 222	62.07	21.68	4.24	12.00
21	212 109 625	26.68	17.25	13.76	42.31
31	156 073 393	35.16	12.05	8.19	44.60
32		26.96	9.39	13.91	49.74
42	28 896 531	28.34	10.89	50.28	10.49
52	12 468 234	24.55	11.22	13.55	50.67
53		24.55	11.22	13.55	50.67
62	1 068 054	24.55	11.22	13.55	50.67

Note: AMT annual miles traveled.

Table 6
Distribution of the type of fuel according to vehicle class.

ID	Type of fuel	
	Gasoline	Diesel
11	1.00	0.00
21	0.96	0.04
31	0.71	0.29
32	0.72	0.28
42	0.00	1.00
52	0.00	1.00
53	0.00	1.00
62	0.00	1.00

Table 7
Distribution of the miles traveled factors by month.

Month	AMT factor
January	0.093429
February	0.092325
March	0.088272
April	0.086516
May	0.082302
June	0.080228
July	0.069713
August	0.073086
September	0.080214
October	0.081732
November	0.084681
December	0.087503

Note: AMT Annual miles traveled.

One of the necessary input variables to obtain the mobile emissions inventory corresponds to the meteorological data from the analysis area, shown in Tables 8 and 9 for the years 2005 and 2013, respectively. Various studies indicate that the temperature of the environment has an effect on pollutant emissions such as CO and NOx, including diesel

Table 8
Meteorological data from the study area for the year 2005.

Month	T max (°F)	T min (°F)	T dew (°F)	Pressure (hPa)
January	73.4	46.4	48.2	1027
February	82.4	50.0	53.6	1014
March	71.6	44.6	51.8	1018
April	64.4	37.4	42.8	1019
May	55.4	42.8	42.8	1014
June	51.8	41.0	42.8	1016
July	53.6	39.2	42.8	1019
August	55.4	39.2	41.0	1017
September	59.0	39.2	41.0	1021
October	60.8	41.0	44.6	1020
November	66.2	46.4	50.0	1017
December	69.8	46.4	51.8	1016

Table 9
Meteorological data from the study area for the year 2013.

Month	T max (°F)	T min (°F)	T dew (°F)	Pressure (hPa)
January	82.4	50.0	55.4	1014
February	77.0	48.2	53.6	1015
March	73.4	44.6	50.0	1017
April	66.2	44.6	50.0	1017
May	57.2	42.8	46.4	1018
June	51.8	37.4	42.8	1020
July	51.8	37.4	41.0	1020
August	53.6	37.4	39.2	1021
September	59.0	37.4	41.0	1020
October	64.4	41.0	46.4	1019
November	66.2	42.8	48.2	1018
December	69.8	48.2	50.0	1015

vehicles (Weilenmann et al., 2009; Franco et al., 2013). In the present study, it was assumed that the temperature and average relative humidity values by hour for each month were equal for the areas of study. It is important to include that a tool was employed with a Microsoft Excel format called "Meteorological data converter mobile6," given by the EPA website (EPA, 2013) to obtain the aforementioned values. To do this, The Weather Underground, Inc. (The Weather Underground) and the data were used for minimum and maximum average annual temperatures for the years 2005 and 2013, respectively. In addition, the values corresponding to the dew temperature and the average atmospheric pressure for the same periods were used. The data from the month of December 2013 was assumed as the same as 2012.

On the other hand, it is necessary to know the formulation of the fuels used for the simulation. Within MOVES, fuel formulation adjusts the emissions according to the fuel formulation within a specific fuel type. Fortunately, Chile has improved fossil fuels restricts the sulfur content in diesel fuel, reducing gradually from values as high as 2000 ppm by 2004 to 50 ppm by 2013, while for gasoline sulfur reduction came in 2004 from 100 ppm to 15 ppm by 2013. The Chilean government hopes that by the end of 2015, the sulfur content in diesel reaches values as low as 15 ppm, making the vehicle type used in Chile are very similar to those used in the United States in terms of fuel and engine regulations.

The values shown in Table 10 with respect to the formulation of the fuels occupied were obtained from the publications by the Ministry of the Economy, Production and Regulation (Ministerio de Economía, 2004) and from the Chilean National Fuel Company (ENAP, 2013). The Reid Vapor Pressure (RVP) varies with the ambient temperature, and in this study the averages of the 2005 and 2013 were used. The Methyl Tert-Butyl Ether, Ethyl Tert-Butyl Ether, DiMethyl Ether, and Ethanol contents in gasoline were considered null because of the lack of information on the topic. It was also assumed that only one type of fuel is used in each category.

With respect to the formulation of the biodiesel, the values were changed corresponding to the sulfur content in the diesel blends established for the year 2013. The values for cetane and content of aromatics were not used, since MOVES does not adjust emissions to these fuel properties (EPA, 2012a, 2012b). In Table 11, the sulfur content is shown for the blends of biodiesel considered. It was assumed that the density value of pure diesel (ENAP, 2013) is 0.85 g/cm^3 and of biodiesel 0.86 g/cm^3 (Ministerio de Economía, 2008).

Table 10
Formulation of the fuels for the year 2005 and 2013 at Temuco and Padre Las Casas.

Category	2005		2013	
	Gasoline	Diesel	Gasoline	Diesel
RVP	10–12	0	8–10	0
Sulfur (ppm)	100	1250	15	50
Aromatics (% volume)	50	0	38	0
Olefines (% volume)	40	0	12	0
Benzene (% volume)	1	0	1	0
e200 (%)	41.09	0	41.09	0
e300 (%)	83.09	0	83.09	0
T50 (°F)	250	0	250	0
T90 (°F)	374	0	370	0

Note: RVP = 10 for October to April and RVP = 12 for May to September in 2005.
Note: RVP = 8 for September to March and RVP = 10 for April to August in 2013.

Table 11
Sulfur content in the biodiesel blends.

Mixes	BD0	BD1	BD4	BD8	BD12	BD20
Biodiesel (%)	0.00	1.0	4.0	8.0	12.0	20.0
Diesel (%)	100.0	99.0	96.0	92.0	88.0	80.0
Sulfur (ppm)	50.0	47.5	39.9	29.9	19.9	0

Table 12
Distribution of the activity of driving factors by zone in Temuco and Padre Las Casas.

Zone	startAlloc factor	idleAlloc factor	SHPAlloc factor
I	0.05	0.05	0.05
II	0.10	0.10	0.10
III	0.70	0.70	0.70
IV	0.10	0.10	0.10
V	0.05	0.05	0.05

Table 12 shows the distribution of the vehicle operation modes regarding the starting mechanism (StartAlloc), prolonged inactivity (idleAlloc), and time dedicated to parking (SHPAlloc) in the study area. When a vehicle is turned on, after being parked all night, the motor, the oil, and the catalytic converter have a lower temperature than optimum one to achieve system efficiency to control the emissions. In this moment, the vehicle can present high emissions than the average in pollutants, such as CO and particulate matter (Dowling et al., 2005). Thus, the distribution data mentioned earlier were estimated following the geographic and economic characteristics of the study area, given the absence of real data.

Finally, the same default MOVES maintenance and inspection data was assumed, because of the lack of information in these aspects currently in the study area.

4. Results and discussion

To compare and analyze our estimated 2005 emissions with the Chilean emission inventory obtained with MODEM, first of all, Table 13 shows the average emission factors of diesel buses and trucks registered for the year 2005. It is observed that there were differences in all pollutants shown, with values lower in MOVES than MODEM for buses, but for trucks emission factors were higher in MOVES. One reason may be the classification of vehicle classes in both simulation programs (Gurjar et al., 2010). Finding similarities among the analyzed vehicles can be complex, because MOVES classifies the vehicles according to their engine characteristics and trip purpose. On the other hand, MODEM classifies the vehicles according to their particular technological characteristics and type of engine, as well as MODEM groups those vehicle classes that have variable and fixed flow within the zone of analysis called "arc" (DICTUC, 2010). Another influential factor may be the age of the vehicle fleet. To perform the simulation in MOVES, data for this variable was entered as 20 years of age, allocating factors of vehicles in distribution each year. Moreover, DICTUC's study does not reflect detail on this variable, so it is presumed that there are differences in this respect in both investigations as is shown in Table 13.

Table 14 shows the 2005 emissions inventory results estimated by MOVES for the Temuco and Padre Las Casas counties, and a comparison is presented with respect to the values obtained by MODEM. The most similar emission values between these two models were CO_2 and NOx, with 3 and 8% in difference, respectively. On the other hand, SO_2 registered the highest value of difference, rising 31% over the 2005

Table 13
Emission factors MOVES for the year 2013.

ID	MODEL	PM_{10} (g/mi)	$PM_{2.5}$ (g/mi)	NOx (g/mi)	SO_2 (g/mi)
42	MODEM	1.54	1.42	24.97	1.20
	MOVES	0.68	0.66	16.33	1.20
52	MODEM	0.52	0.47	4.62	0.40
	MOVES	0.74	0.72	12.15	0.97
53	MODEM	1.03	0.95	9.79	0.78
	MOVES	0.74	0.72	11.64	0.92
62	MODEM	1.05	0.96	17.06	1.27
	MOVES	1.43	1.38	29.56	2.05

Table 14
Emissions from MOVES and MODEM for the year 2005.

Pollutant	MODEM 2005	MOVES 2005	Relative error (%)
NH_3 (ton)	18.24	13.85	−24
CO_2 equiv. (ton)	161,304.54	166,188.81	+3
CO (ton)	9829.00	7342.10	−25
NOx (ton)	1271.74	1377.30	+8
PM_{10} (ton)	53.12	47.18	−11
$PM_{2.5}$ (ton)	48.86	45.54	−7
SO_2 (ton)	48.48	63.50	+31

Chilean Emission Inventory for Temuco and PLCs. This could be due to the age of the vehicle fleet in the study areas (Gurjar et al., 2010). This generates emission factors that are higher than new vehicles, given the advanced deterioration of the motors, and the resulting unfavorable combustion for the emission of toxic substances. In addition, the results obtained regarding particulate matter was found between 7–11% lower than MODEM model.

As a result, input guidelines were established to obtain MOVES emissions results in Temuco and Padre Las Casas counties, having specified variables for year 2013 with the meteorological data, the age of the vehicle fleet, and the miles traveled by the vehicles, as well as the formula of the fuels occupied.

Table 15 shows the results of the emissions inventory of mobile sources for 2013 using gasoline and diesel as fuel using MOVES. The vehicles that use gasoline are those responsible for the majority of the emission of NH_3, equivalent CO_2, and CO. In contrast, the PM and the SO_2 are emitted in largely by those that use diesel fuel. The results of NOx and BaP were similar in agreement with the type of fuel used, resulting in 54 and 61% the diesel contribution, respectively. The values obtained of SO_2 are significantly lower than the 2005 results, due mainly to the reduction of the sulfur content in the fuels (Tan et al., 2013), being a positive measure for the improvement of the air quality for these areas. On the other hand, the emission of PM_{10} and $PM_{2.5}$ decreased in 15 and 16%, respectively, despite the fact that the number of miles traveled annually increased by 47% from one period to the next. An improvement in the age of the vehicle fleet and lower sulfur content (Tan et al., 2013) influenced the obtained results.

A significant contribution of this study was in obtaining 2013 mobile source BaP emissions for the first time in Chilean urban areas, and criteria pollutants using MOVES model. Implementing this model in Chile would then permit the estimation of the BaP and other emissions from mobile sources, which can be an important tool for policy making on air quality and air pollution control in Chile.

By 2013, the average emission factors for NOx, PM_{10}, $PM_{2.5}$, SO_2, and BaP were obtained as shown in Table 16. This table shows how the use of biodiesel changes emission for these pollutants; those differences are due to the characteristics of this biofuel. Note that only one type of biodiesel was considered in this study, hence the trend recorded showing the general behavior. There are studies that reflect different behaviors depending on the type of biodiesel used and added additives to improve the combustion (Tsai et al., 2014).

Table 15
Total emissions for the year 2013 using gasoline and diesel in Temuco and Padre Las Casas counties.

Pollutant	Gasoline	Diesel	Total
NH_3 (ton)	14.19	2.01	16.21
CO_2 equiv. (ton)	140,828.61	84,940.64	225,769.25
CO (ton)	4447.44	309.54	4756.99
NO_x (ton)	469.13	549.62	1018.75
PM_{10} (ton)	7.16	32.85	40.01
$PM_{2.5}$ (ton)	6.59	31.85	38.44
SO_2 (ton)	1.25	2.85	4.14
BaP (kg)	1.12	1.73	2.85

Table 16
Emission factors of MOVES using biodiesel blends for the year 2013.

	NOx (g/mi)	PM_{10} (g/mi)	$PM_{2.5}$ (g/mi)	SO_2 (g/mi)	BaP (μg/mi)
BD 0					
42	10.0888	0.528	0.513	0.05	22.684
52	5.3214	0.263	0.255	0.04	21.786
53	5.8303	0.317	0.307	0.03	27.759
62	14.6242	0.528	0.511	0.07	12.441
BD1					
42	10.0998	0.517	0.502	0.04	22.507
52	5.3274	0.258	0.250	0.03	21.616
53	5.8364	0.310	0.301	0.03	27.542
62	14.6416	0.516	0.504	0.07	12.344
BD4					
42	10.133	0.511	0.496	0.04	21.976
52	5.345	0.254	0.247	0.03	21.106
53	5.856	0.306	0.297	0.03	26.893
62	14.690	0.511	0.498	0.06	12.053
BD8					
42	10.181	0.493	0.478	0.03	21.268
52	5.370	0.245	0.238	0.02	20.426
53	5.884	0.295	0.286	0.02	26.027
62	14.759	0.492	0.478	0.04	11.665
BD12					
42	10.222	0.477	0.463	0.02	20.560
52	5.392	0.237	0.230	0.01	19.747
53	5.907	0.286	0.277	0.01	25.160
62	14.819	0.478	0.463	0.03	11.276
BD20					
42	10.311	0.443	0.430	0.00	19.145
52	5.438	0.221	0.215	0.00	18.387
53	5.958	0.265	0.257	0.00	23.428
62	14.948	0.442	0.429	0.00	10.500

Fig. 2 shows the difference in the percentage of the emission of NOx, CO, PM_{10}, $PM_{2.5}$ and BaP, using biodiesel mixes in vehicles that used diesel during 2013. The behavior obtained corresponds to that expressed in diverse studies of literature mentioned earlier. The maximum value of the emission reductions of $PM_{2.5}$, CO, and BaP was around 15%. The increase in NOx emission was 2%, approximately.

It should be noted that variations in biodiesel emissions were similar for each vehicle model year of study. This result is not consistent with the EPA's study (EPA, 2002) in which different percentages of emissions were obtained for different vehicles model year. Giakoumis obtained variations in PM, CO and NOx emissions for different vehicles period noticing of use in blends above 20% by volume of biofuel as shown in Figs. 14–16 of that investigation (Giakoumis, 2012). The causes of this behavior are attributable to the type of fuel injection engine and the antipollution system in each year of use (Yanowitz and McCormick, 2009; Giakoumis, 2012).

Improvements are needed to calculate emissions by MOVES using biodiesel, in which more number of additive variables that affect emissions have to be considered, such as cetane, viscosity, density and type of biodiesel, among others, which have been widely studied (Park et al., 2008). It is suggested that the differences in the emissions are not only ascribed to a factor of variation.

In spite of the differences of this magnitude in the biggest cities such as Santiago, the emissions can be considerable given that the vehicular activity is far superior to that of Temuco and Padre Las Casas. MOVES would help to estimate emissions inventories on mobile sources to this capital city and could bring information that will affect a better management of the air quality in critical cities in Chile in general.

5. Conclusions

The present study demonstrated the possibility of using MOVES to carry out emission inventories from mobile sources for the Temuco and Padre Las Casas counties, Chile. It was shown that there was a reduction from the year 2005 to the year 2013 for the emissions of

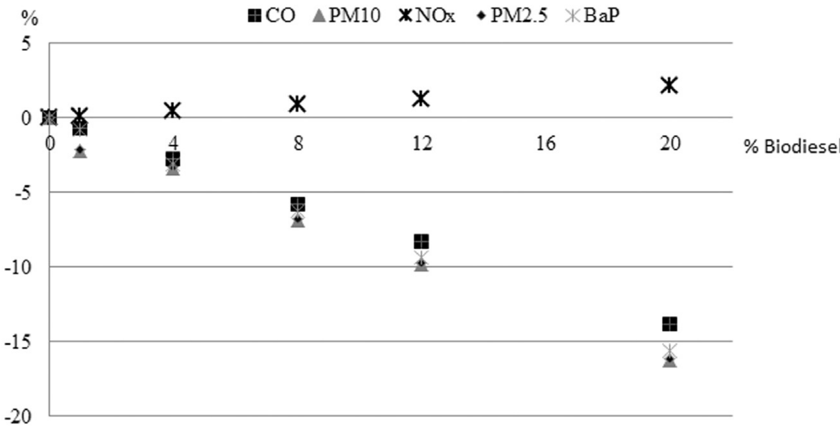

Fig. 2. Differences in emissions using biodiesel blends.

PM_{10}, $PM_{2.5}$, SO_2, and CO, thanks to the improvements in fuels, and also the antiquity of the vehicle fleet.

Upon realization of simulations using biodiesel blends in diesel, the expected behavior was achieved in contaminant emissions, specifically reducing PM, CO, and BaP around 15% at the maximum concentration of biofuel. Also the NOx values increased up to 2%, showing the effect that biodiesel produces in the emissions of this contaminant.

In this manner, it was possible to use a model to obtain emissions inventories from mobile sources that will help in managing the air quality in Chile, given that the study boasts information on an ample range of pollutants.

Acknowledgment

We acknowledge the FONDECYT Project N° 1120791 for supporting this study.

References

Acevedo, F., Pizzul, L., Castillo, M.D., Gonzalez, M.E., Cea, M., Gianfreda, L., Diez, M.C., 2010. Degradation of polycyclic aromatic hydrocarbons by free and nanoclay-immobilized manganese peroxidase from *Anthracophyllum discolor*. Chemosphere 80 (3), 271–278.

Acevedo, F., Pizzul, L., Castillo Mdel, P., Cuevas, R., Diez, M.C., 2011. Degradation of polycyclic aromatic hydrocarbons by the Chilean white-rot fungus *Anthracophyllum discolor*. J. Hazard. Mater. 185 (1), 212–219.

Aguilera, P., Briceno, G., Candia, M., Mora Mde, L., Demanet, R., Palma, G., 2009. Effect of dairy manure rate and the stabilization time of amended soils on atrazine degradation. Chemosphere 77 (6), 785–790.

ATSDR, 2013. Agency for toxic substances and disease registry, website: http://www.atsdr.cdc.gov/spl/ March 2014, from http://www.atsdr.cdc.gov/spl/.

Bari, M.A., Baumbach, G., Brodbeck, J., Struschka, M., Kuch, B., Dreher, W., Scheffknecht, G., 2011. Characterisation of particulates and carcinogenic polycyclic aromatic hydrocarbons in wintertime wood-fired heating in residential areas. Atmos. Environ. 45 (40), 7627–7634.

Cavanagh, J.A.E., Brown, L., Trought, K., Kingham, S., Epton, M.J., 2007. Elevated concentrations of 1-hydroxypyrene in schoolchildren during winter in Christchurch, New Zealand. Sci. Total Environ. 374 (1), 51–59.

Cereceda-Balic, F., Fadic, X., Llanos, A.L., Dominguez, A.M., Guevara, J.L., Vidal, V., Diaz-Robles, L.A., Schiappacasse, L.N., Etcharren, P., 2012. Obtaining polycyclic aromatic hydrocarbon concentration ratios and molecular markers for residential wood combustion: Temuco, a case study. J. Air Waste Manage. Assoc. 62 (1), 44–51.

Clark, N.N., Kern, J.M., Atkinson, C.M., Nine, R.D., 2002. Factors affecting heavy-duty diesel vehicle emissions. J. Air Waste Manage. Assoc. 52 (1), 84–94.

CONAMA, 2008. Comisión Nacional del Medio Ambiente. Actualización del inventario de emisiones atmosféricas en las comunas de Temuco y Padre Las Casas. Comisión Nacional del Medio Ambiente, Región de La Araucanía.

CONAMA, 2009. Comisión Nacional del Medio Ambiente. Guía metodológica para la estimación de emisiones atmosféricas de fuentes fijas y móviles en el registro de emisiones y transferencia de contaminantes. 978-956-7204-36-6.

Díaz-Robles, L.A., 2013. Emission scenarios and the health risks posed by priority mobile air toxics in an urban to regional area: an application in Nashville, Tennessee. Aerosol Air Qual. Res. 15 (1), 306–318.

Díaz-Robles, L.A., Fu, J.S., Reed, G.D., 2008a. Modeling and source apportionment of diesel particulate matter. Environ. Int. 34 (1), 1–11.

Díaz-Robles, L.A., Ortega, J.C., Fu, J.S., Reed, G.D., Chow, J.C., Watson, J.G., Moncada-Herrera, J.A., 2008b. A hybrid ARIMA and artificial neural networks model to forecast particulate matter in urban areas: the case of Temuco, Chile. Atmos. Environ. 42 (35), 8331–8340.

Díaz-Robles, L.A., Fu, J.S., Reed, G.D., DeLucia, A.J., 2009. Seasonal distribution and modeling of diesel particulate matter in the Southeast US. Environ. Int. 35 (6), 956–964.

Díaz-Robles, L.A., Fu, J.S., Vergara-Fernández, A., Etcharren, P., Schiappacasse, L.N., Reed, G.D., Silva, M.P., 2014. Health risks caused by short term exposure to ultrafine particles generated by residential wood combustion: a case study of Temuco, Chile. Environ. Int. 66, 174–181.

DICTUC, 2010. Actualización metodológica MODEM–MODEC para el Gran Santiago.

Dohanich, F.A., Hudak, P.F., Atkinson, S.F., 2004. On-road remote sensing of motor vehicle emissions: associations between exhaust pollutant levels and vehicle year. Int. J. Environ. Stud. 61 (2), 139–143.

Dowling, R.G., Program, N.C.H.R., Board, N.R.C.T.R., Highway, A.A.O.S., Officials, T., 2005. Predicting air quality effects of traffic-flow improvements: final report and user's guide. Transp. Res. Board, 92–96.

Dwivedi, G., Jain, S., Sharma, M.P., 2011. Impact analysis of biodiesel on engine performance—a review. Renew. Sust. Energ. Rev. 15 (9), 4633–4641.

ENAP, 2013. Inversionistas y Mercado. Productos Retrieved Noviembre 2013, from http://www.enap.cl/pag/67/992/productos.

EPA, 2002. A comprehensive analysis of biodiesel impacts on exhaust emissions. U.S. Environmental Protection Agency, Office of Transportation and Air Quality (EPA420-P-02-001).

EPA, 2012a. Motor Vehicle Emission Simulator (MOVES) User Guide for MOVES2010b (EPA-420-B-12-001b).

EPA, 2012b. Using MOVES to prepare emission inventories in state implementation plans and transportation conformity: technical guidance for MOVES2010, 2010a and 2010b. Transportation and Climate Division. Office of Transportation and Air Quality.

EPA, 2013. Meteorological data converter MOBILE6 (XLS) Retrieved November 2013, 2013, from http://www.epa.gov/otaq/models/moves/tools.htm#movesinput.

Escobedo, F.J., Wagner, J.E., Nowak, D.J., De la Maza, C.L., Rodriguez, M., Crane, D.E., 2008. Analyzing the cost effectiveness of Santiago, Chile's policy of using urban forests to improve air quality. J. Environ. Manag. 86 (1), 148–157.

Faiz, A., Weaver, C.S., Walsh, M.P., 1996. Air pollution from motor vehicles: standards and technologies for controlling emissions. World Bank.

FHWA, 2013. Flexibility in Highway Design, Federal Highway Administration, U.S. Department of Transportation. Website: http://www.fhwa.dot.gov/environment/publications/flexibility/ch03.cfm Retrieved October 2013, 2013, from http://www.fhwa.dot.gov/environment/publications/flexibility/ch03.cfm.

Franco, V., Kousoulidou, M., Muntean, M., Ntziachristos, L., Hausberger, S., Dilara, P., 2013. Road vehicle emission factors development: a review. Atmos. Environ. 70, 84–97.

Garcia-Chevesich, P.A., Alvarado, S., Neary, D.G., Valdes, R., Valdes, J., Aguirre, J.J., Mena, M., Pizarro, R., Jofre, P., Vera, M., Olivares, C., 2014. Respiratory disease and particulate air pollution in Santiago, Chile: contribution of erosion particles from fine sediments. Environ. Pollut. 187, 202–205.

Giakoumis, E.G., 2012. A statistical investigation of biodiesel effects on regulated exhaust emissions during transient cycles. Appl. Energy 98, 273–291.

Giannelli, R., Nam, E.K., Helmer, K., Younglove, T., Scora, G., Barth, M., 2005. Heavy-duty diesel vehicle fuel consumption modeling based on road load and power train parameters. SAE International.

Guldner, R., 2013. Opening speech Annual Meeting on Nuclear Technology 2013 14 to 16 May 20131 Berlin, Germany. Atw Int. J. Nucl. Power 58 (7), 410–411.

Gurjar, B., Molina, L., Ojha, C., 2010. Air pollution: health and environmental impacts. Taylor & Francis.

INE, 2013. Instituto Nacional de Estadísticias Región de la Araucanía, Chile Retrieved Octubre 2013, 2013, from http://www.inearaucania.cl/contenido.aspx?id_contenido=66.

Karavalakis, G., Stournas, S., Bakeas, E., 2009. Light vehicle regulated and unregulated emissions from different biodiesels. Sci. Total Environ. 407 (10), 3338–3346.

Karavalakis, G., Boutsika, V., Stournas, S., Bakeas, E., 2011. Biodiesel emissions profile in modern diesel vehicles. Part 2: effect of biodiesel origin on carbonyl, PAH, nitro-PAH and oxy-PAH emissions. Sci. Total Environ. 409 (4), 738–747.

Koc, A.B., Abdullah, M., 2013. Performance and NOx emissions of a diesel engine fueled with biodiesel–diesel–water nanoemulsions. Fuel Process. Technol. 109, 70–77.

Koupal, J., Beardsley, M., Brzezinski, D., Warila, J., Faler, W., 2010. U.S. EPA's MOVES2010 vehicle emission model: overview and considerations for international application. U.S. Environmental Protection Agency, Office of Transportation and Air Quality-Fluid & Reason LLC.
Kumar, N., Varun, Chauhan, S.R., 2013. Performance and emission characteristics of biodiesel from different origins: a review. Renew. Sust. Energ. Rev. 21, 633–658.
Leiva, G.M.A., Santibañez, D.A., Ibarra, E.S., Matus, C.P., Seguel, R., 2013. A five-year study of particulate matter ($PM_{2.5}$) and cerebrovascular diseases. Environ. Pollut. 181, 1–6.
Lewtas, J., 2007. Air pollution combustion emissions: characterization of causative agents and mechanisms associated with cancer, reproductive, and cardiovascular effects. Mutat. Res. Rev. Mutat. Res. 636 (1–3), 95–133.
McCormick, R.L., Graboski, M.S., Alleman, T.L., Herring, A.M., Tyson, K.S., 2001. Impact of biodiesel source material and chemical structure on emissions of criteria pollutants from a heavy-duty engine. Environ. Sci. Technol. 35 (9), 1742–1747.
Ministerio de Economía, F. y. R., 2008. Aprueba definiciones y especificaciones de calidad para la producción, importación, transporte, almacenamiento, distribución y comercialización de bioetanol y biodiesel. F. y. R. Ministerio de Economía, Diario Oficial de la Respública de Chile. No 11.
Ministerio de Economía, F. y. R., Chile, 2004. Calidad de los combustibles. Diario Oficial de la República de Chile. No 133.
Nicolas Schiappacasse Poyanco, L.A.D.-R., Cereceda-Balic, Francisco, Silva, Paola Silva Schwartau, 2013. Health impacts in South-central Chile due to misuse of wood-burning stoves. Electron. J. Energy Environ. http://dx.doi.org/10.7770/ejee-V1N3-art685.
Nielsen, T., Jørgensen, H.E., Larsen, J.C., Poulsen, M., 1996. City air pollution of polycyclic aromatic hydrocarbons and other mutagens: occurrence, sources and health effects. Sci. Total Environ. 189–190, 41–49.
Nussbaumer, T., 2003. Combustion and co-combustion of biomass: fundamentals, technologies, and primary measures for emission reduction. Energy Fuel 17 (6), 1510–1521.
Nussbaumer, T., Hasler, P., 1999. Formation and behavior of aerosols from wood combustion. Holz Roh Werkst. 57 (1), 13–22.
Paredes, M., Gonzalez, K., Figueroa, J., Montiel-Eulefi, E., 2013. Immunomodulatory effect of prolactin on Atlantic salmon (*Salmo salar*) macrophage function. Fish Physiol. Biochem. 39 (5), 1215–1221.
Park, S.H., Yoon, S.H., Suh, H.K., Lee, C.S., 2008. Effect of the temperature variation on properties of biodiesel and biodiesel–ethanol blends fuels. Oil Gas Sci. Technol. Rev. Energ. Nouv. 63 (6), 737–745.
Pozo, K., Estellano, V.H., Harner, T., Diaz-Robles, L., Cereceda-Balic, F., Etcharren, P., Pozo, K., Vidal, V., Guerrero, F., Vergara-Fernández, A., 2015. Assessing Polycyclic Aromatic Hydrocarbons (PAHs) using passive air sampling in the atmosphere of one of the most wood-smoke-polluted cities in Chile: the case study of Temuco. Chemosphere 134, 475–481.
Romero-Lankao, P., Qin, H., Borbor-Cordova, M., 2013. Exploration of health risks related to air pollution and temperature in three Latin American cities. Soc. Sci. Med. 83, 110–118.
Sanhueza, P.A., Torreblanca, M.A., Diaz-Robles, L.A., Schiappacasse, L.N., Silva, M.P., Astete, T.D., 2009. Particulate air pollution and health effects for cardiovascular and respiratory causes in Temuco, Chile: a wood-smoke-polluted urban area. J. Air Waste Manage. Assoc. 59 (12), 1481–1488.
Surawski, N.C., Miljevic, B., Ayoko, G.A., Elbagir, S., Stevanovic, S., Fairfull-Smith, K.E., Bottle, S.E., Ristovski, Z.D., 2011. Physicochemical characterization of particulate emissions from a compression ignition engine: the influence of biodiesel feedstock. Environ. Sci. Technol. 45 (24), 10337–10343.
Symeonidis, P., Ziomas, I., Proyou, A., 2003. Emissions of air pollutants from the road transport sector in Greece: year to year variation and present situation. Environ. Technol. 24 (6), 719–726.
Tan, P.-Q., Zhao, J.-Y., Hu, Z.-Y., Lou, D.-M., Du, A.-M., Du, D.-M., 2013. Effects of fuel properties on exhaust emissions from diesel engines. J. Fuel Chem. Technol. 41 (3), 347–355.
The Weather Underground, I., . Weather underground Retrieved Noviembre 2013, from http://www.wunderground.com/.
Tsai, J.H., Chen, S.J., Huang, K.L., Lin, Y.C., Lee, W.J., Lin, C.C., Lin, W.Y., 2010. PM, carbon, and PAH emissions from a diesel generator fuelled with soy–biodiesel blends. J. Hazard. Mater. 179 (1–3), 237–243.
Tsai, J.H., Chen, S.J., Huang, K.L., Lin, W.Y., Lee, W.J., Lin, C.C., Hsieh, L.T., Chiu, J.Y., Kuo, W.C., 2014. Emissions from a generator fueled by blends of diesel, biodiesel, acetone, and isopropyl alcohol: analyses of emitted PM, particulate carbon, and PAHs. Sci. Total Environ. 466–467, 195–202.
Tsapakis, M., Lagoudaki, E., Stephanou, E.G., Kavouras, I.G., Koutrakis, P., Oyola, P., von Baer, D., 2002. The composition and sources of $PM_{2.5}$ organic aerosol in two urban areas of Chile. Atmos. Environ. 36 (23), 3851–3863.
Weilenmann, M., Favez, J.-Y., Alvarez, R., 2009. Cold-start emissions of modern passenger cars at different low ambient temperatures and their evolution over vehicle legislation categories. Atmos. Environ. 43 (15), 2419–2429.
Yanowitz, J., McCormick, R.L., 2009. Effect of biodiesel blends on North American heavy-duty diesel engine emissions. Eur. J. Lipid Sci. Technol. 111 (8), 763–772.