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Nicoletta Lotrecchiano, Renato Ciampa, Aristide Giuliano, Daniele Sofia

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Nicoletta Lotrecchiano

DIIN – Department of Industrial Engineering,
Faculty of Engineering,
University of Salerno,
Via Giovanni Paolo II 132, Fisciano,
SA, Italy
Email: nlotrecchiano@unisa.it

Renato Ciampa

Research and Development Department,
Centro Diagnostico Baronia,
Frigento, AV, Italy
Email: info@cdbaronia.it

Aristide Giuliano

Laboratory Biorefineries and Green Chemistry,
Italian National Agency for New Technologies,
Energy and Sustainable Economic Development,
ENEA,
S.S. 106 Ionica, km 419+500,
Rotondella, MT, Italy
Email: aristide.giuliano@enea.it

Daniele Sofia*

DIIN – Department of Industrial Engineering,
Faculty of Engineering,
University of Salerno,
Via Giovanni Paolo II 132, Fisciano,
SA, Italy
and
Research and Development Department,
Sense Square,
Corso Garibaldi 33, Salerno,
SA, Italy
Email: dsofia@unisa.it
*Corresponding author

Abstract: The environmental status is defined by the combination of information about air pollution and waste production and management. This paper aims to compare the percentage of waste disposal in Italy with air quality. For each Italian region, the percentage of waste disposal and air quality were analysed. For some more interesting regions like Trentino South-Tyrol, Piedmont, Veneto, Lombardy, Lazio, Marche, Umbria, Abruzzo, Campania, Basilicata, Apulia, and Sicily relationship were highlighted taking into account citizens' concerns about air quality. It is clear, after analysing the data, that in 2012–2017 the environmental awareness of the Italian population has increased with a consequent increase in the percentage of waste disposal and with the improvement of air quality.

Keywords: Italy; waste disposal; air quality; environment; particulate matter; NO_2.

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Biographical notes: Nicoletta Lotrecchiano is a third year PhD student in Industrial Engineering at University of Salerno. Her main research areas are air quality analytics, big data management and pollution dispersion. Among her expertise and experiences there are data processing and evaluation of possible emission sources of pollution in urban and industrial context, design of integrated parts using 3D software, and statistical analysis of pollution data. She is the author of 13 publications in international journals.

Renato Ciampa is an environmental expert who has been operating for over 22 years in the renewable energy sector, in the recovery of waste, in the reduction of atmospheric pollution and in the management of various research and development projects in these sectors. He is also a class A trainer and the founder of the ethical brand 'eco' and administrator of several SMEs.

Aristide Giuliano is a researcher at the ENEA-TRISAIA Research Center-Laboratory of Biorefineries and Green Chemistry. He studies the process design and optimisation of multi-product lignocellulosic biorefineries to identify the bio-based high-added value compounds ready for commercialisation. He is the author of 32 publications in international journals and he is the inventor of one international patent.

Daniele Sofia obtained his PhD in Industrial Engineering (Chemical Engineering Curriculum) at the University of Salerno. During the PhD thesis 'Topics towards SLS process of ceramic powders' he has studied the effect of several material and process parameters to some of the SLS process fundamental phenomena of ceramic materials and developed his own experimental set up to spread powder and to selectively sinter them with a CO_2 laser beam. He has also developed many patents on an innovative sensing unit for atmospheric pollution, obtained by measuring several physical parameters and published 33 studies in international journals.

1 Introduction

The World Health Organization estimates that every year 3.7 million deaths are caused by outdoor pollution in low to medium income countries and western European countries, USA, and Australia despite their progress in the reduction of industrial and traffic emissions. The healthcare risks of particulate matter on the human body are well-known (Cassee et al., 2013; Cascio, 2016), and its effect on depressive disorders is proved (Acikgoz et al., 2013). The production of photochemical smog depends, therefore, on the atmospheric concentrations of nitrogen oxides and hydrocarbons and is linked closely to emissions due to vehicular traffic. In urban centres, a variable fraction, which can reach 60–80% by mass of fine particulate matter present in the atmosphere, is of secondary origins, such as that resulting from chemical reactions. Starting from primary gaseous pollutants (emitted directly into the atmosphere) such as hydrocarbons and other organic compounds, that secondary (the result of chemical transformations such as ozone and other photochemical pollutants) generate a vast number of compounds in solid or liquid phases such as sulphates, nitrates and organic particles (Sharma et al., 2014). The correct definition of the pollutant concentration dispersed in the air can help the municipalities in traffic management to actuate some policies to deliver sustainable mobility in urban areas (Centrone and Coslovich, 2008; Valeri et al., 2016). In an urban context, the source of pollution is not only the vehicular traffic given by cars but also the public transport network should be considered it can promote peak episodes of pollution due to its obsolete technology. This type of contribution to air pollution must be forecasted with a statistical analysis method (Nathan and Reddy, 2012; Catalano et al., 2016). Each country should provide incisive environmental policies and programs requiring knowledge for citizens, access to technology, and policy enforcement. The implementation of the new green type of regulation, as the air pollution integrated assessment models (IAM), to agree with the WHO air pollution recommended standards, can benefit all the countries. Moreover, IAM and can be used to determine how emissions should be reduced to protect human health and the environment efficiently (Miranda et al., 2016; Guariso et al., 2016; Slovic and Ribeiro, 2018). The strategies to improve air quality and reduce the pollution effect on human health are manifold and customised for each sector, such as the public and private transport sector, whether by road or ship, the industrial sector, the agricultural and food sector, and the household sector (Sofia et al., 2020a).

Italian environmental policy and consciousness increased, and in the last decade, a large number of air quality monitoring networks with high time-space resolution have been installed on the Italian territory supported by citizens and singles municipalities to monitor its cities (Sofia et al., 2018a, 2018b). One of the leading environmental themes discussed with air quality is the problem of municipal waste. Recycling the waste is increasing the efficiency of the waste treatment plant (Morejon et al., 2012) it not only reduces the amount of waste to be sent to the landfill but also reduces the amount of polluting gases emitted from the landfill (Lang, 2005; Talaiekhozani et al., 2016). In waste management, waste disposal indicates a waste collection system that provides for a first separation based on the type of waste by citizens, diversifying it from the general waste. The aim is, therefore, the separation of waste in such a way as to redirect each type of differentiated waste towards the respective most suitable recovery treatment. The treatments used for the generic waste are storage to the landfill or incineration for waste-to-energy recovery. The organic fraction of the municipal solid waste is treated by anaerobic digestion, while the other solid waste fractions as paper, glass, aluminium, steel, plastic, are sent to dedicated treatment plants to be recycled. Waste disposal is preparatory for correct waste management of which represents the first crucial step, but it can be useful only if post-separation treatment infrastructures are present. Correct waste disposal leads to the recycling of all different waste fractions with the advantage of recovering raw materials and energy. In particular, the anaerobic digestion used for the organic fraction treatment is the most used technology to produce biogas that is used in the power plant. The biogas produced by the treatment, as the bio-methane to produce methanol, can be used as an alternative for syngas production with CO_2 emission reduction (Giuliano et al., 2019a). The concept of waste disposal also extends to the valorisation of biomass as feedstock to produce renewable energy towards decarbonisation to reduce environmental pollution as recommended from National Energy and Climate Plan (Sofia et al., 2020b), heat generation, and fuels. In this perspective, the residual biomass characteristic by a single region can be used in properly designed plants for biogas production and energy recovery (Giuliano et al., 2019b).

The state of the environment is determined mainly on measured values, but the population perceives the environmental quality in different ways. Verifying how much and how people sense environmental pollution represents a vital knowledge element to guide the policies of the municipalities but also to provide further emphasis on the citizens' environmental consciousness. Often what is perceived by people is not exactly the real situation due to the lack of information represented by the so-called Nimby syndrome (Giuliano et al., 2018). The air quality monitoring networks represent the tool for the definition of pollution levels and reliable support for industrial activities such as waste treatment plants, biomethane production plants, and other technologies considered to be polluting. These technologies are affected by the Nimby syndrome, which persuades people that they are living in a polluted place due to works of public interests or not, like incinerators, dumps, dangerous material stocks, electric power plants, that fears to have adverse effects on the area where they are or where they will be built. The correct knowledge of the environmental matrix can lead to the social acceptance of the plants, and if necessary, to identify any critical issues in pollution to protect the health of the citizen.

1.1 Aims

The relationship between air pollution and waste recycling define clearly the environmental matrix of a determined area. Founding a correlation between air pollution and waste disposal is given by the need to know how these parameters act on the environment and how they influence each other. Waste disposal and air quality are the two indices of environmental status. The percentage of waste disposal indicates how much waste is separated and how efficient are the treatment and recovery systems. The Air Quality Index (AQI) is representative of the air that citizens are exposed to daily and what are the damages it can cause. The two indices are correlated if it takes into account that both are part of the strategies for improving environmental quality. This type of information represents a powerful tool for the municipalities to held an effective environmental policy. The environmental policy must comprise improvements in waste management plans, air-quality emission reduction, and monitoring. However, there are still very few cases in which the literature on environmental economics pays attention to the relationship between pollution and waste recycling. Air pollution and waste disposal may seem disconnected but, instead, are strictly related to each other (Giovanis, 2015).

This work aims to investigate the air quality and waste disposal behaviour in Italy in the last six years to understand the real Italian situation. After the yearly trend analysis of the AQI and the percentage of waste disposal for each Italian region, the work tries to give a correlation between them.

2 Materials and methods

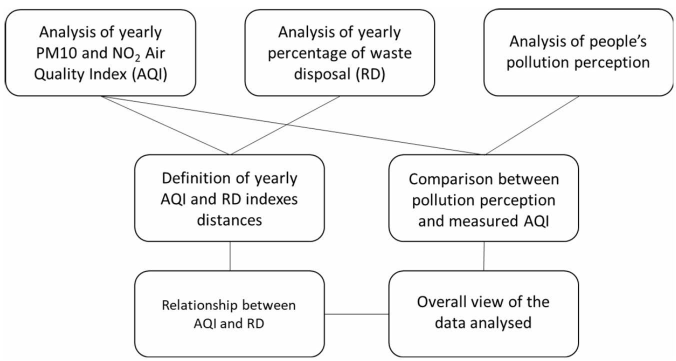
This work is focused on Italian territory. Italy (Figure 1) is a European country consisting of a peninsula delimited by the Alps and surrounded by several islands. The country area is 301,340 km^2 and shares land borders with France, Switzerland, Austria, and Slovenia. Italy is divided into 20 regions.

Figure 1 Italy dived by regions

The open datasets provided by the Italian environment public service were elaborated to investigate the air quality and waste disposal behaviour. The work analyses the percentage of Italian waste disposal and the yearly Italian air quality data in terms of PM_{10} and NO_2 concentrations.

The air quality and waste disposal datasets were initially analysed separately. This allowed the identification of the characteristic trends of the examined variable in the chosen period. To compare the two datasets, synthetic indices have been obtained which describe the correlation between them. Furthermore, the perception of pollution was compared with the real levels of environmental pollution. The survey on the perception of pollution has made it possible to better understand the information deriving from the study of the relationship between air quality and waste disposal. Figure 2 reports the data path analysis.

Figure 2 Algorithm used for the data analysis



2.1 Dataset

2.1.1 Waste disposal

All the data about waste disposal are available on the waste cadastre website (Isprambiente.it, 2018) of the Italian Institute for the Environmental Research and Protection (ISPRA). The data used for the research regards all the 20 Italian regions during the period 2012–2017. The data are collected yearly from the single Italian municipalities that draft the document of the environmental declaration (MUD). Such a document indicates the waste quantities according to their type. The data are subsequently aggregated and elaborated according to Art. 189, Comma 6 of D.Lgs. No. 152/2006 by ISPRA. The data are aggregated on a regional base and reported as tons of waste collected and as a percentage of waste disposal (RD). The data are also divided according to the waste disposal fractions collected as bulky waste, paper/cardboard, organic, wood, metals, plastics, electronic waste (RAEE), textile, glass, and other waste.

The data are reported in Table 1 and indicates that during the year 2012–2017, the percentage of waste disposal in Italy increase by about 15% (Figure 3). According to Eurostat data, in 2017, the average percentage of recycled waste in Europe stands at 37%. In France, the waste disposal stops at around 54%, Germany is at 43%, and Great Britain at 44%. Considering the absolute values, Germany is still the leader in the EU, with about

72.4 million tons of recycled waste. However, Italy, with its 54.6 million tons, is second in the ranking with a substantial boost to growth.

Figure 3 Percentage of waste disposal in Italy for the period 2012–2017 (see online version for colours)

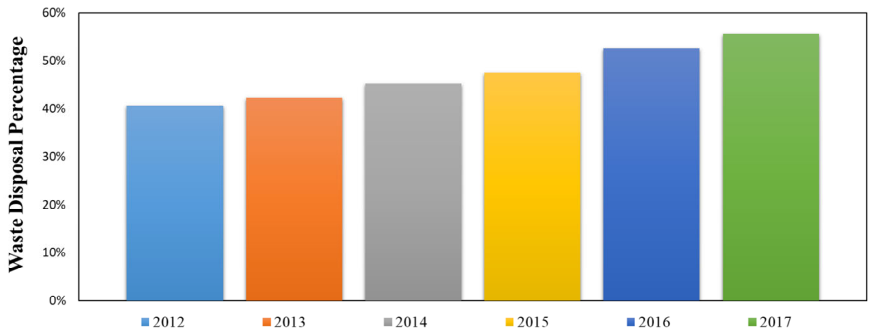
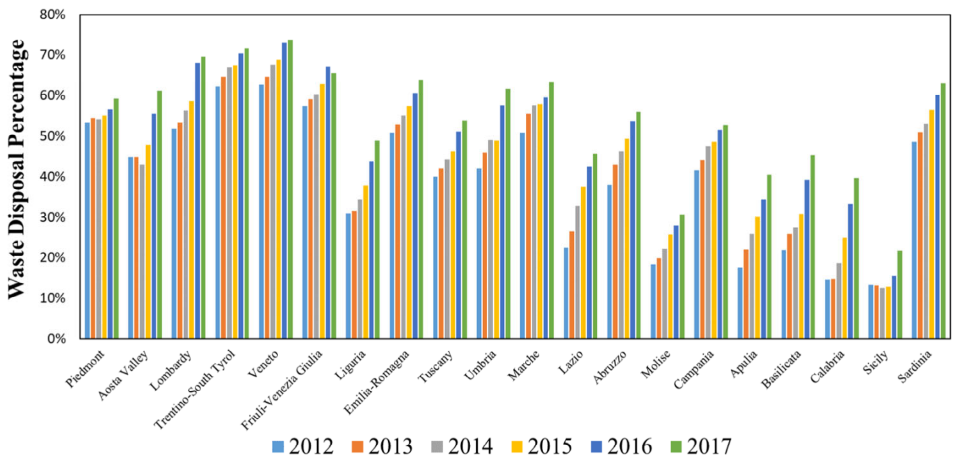


Table 1 Percentage of waste disposal on regional base for the period 2012–2017

Region	*Percentage of waste disposal*					
	Years					
	2012	*2013*	*2014*	*2015*	*2016*	*2017*
Piedmont	53	55	54	55	57	59
Aosta Valley	45	45	43	48	56	61
Lombardy	52	53	56	59	68	70
Trentino-South Tyrol	62	65	67	67	70	72
Veneto	63	65	68	69	73	74
Friuli-Venezia Giulia	58	59	60	63	67	65
Liguria	31	32	34	38	44	49
Emilia-Romagna	51	53	55	58	61	64
Tuscany	40	42	44	46	51	54
Umbria	42	46	49	49	58	62
Marche	51	55	58	58	60	63
Lazio	22	26	33	38	42	46
Abruzzo	38	43	46	49	54	56
Molise	18	20	22	26	28	31
Campania	42	44	48	49	52	53
Apulia	18	22	26	30	34	40
Basilicata	22	26	28	31	39	45
Calabria	15	15	19	25	33	40
Sicily	13	13	12	13	15	22
Sardinia	49	51	53	56	60	63

Analysing the behaviour of the percentage of waste disposal made by a single Italian region (Figure 4), it is possible to note that from 2012 to 2017, all the Italian regions increased the percentage of waste disposal. During 2017 the solid urban waste collected is almost 29.3 million tons (an average of 266.56 kg/inhabitants, –1.3% respect 2016) and the percentage of waste disposal over the total amount of solid urban waste is around 55.51 during 2017 (+3% respect 2016 and +8% respect 2015). According to that reported in Figure 4, the Italian regions that during 2017 reached a percentage of waste disposal greater than 70% are Trentino-South Tyrol and Veneto while Aosta Valley, Lombardy, Friuli-Venezia Giulia, Emilia Romagna, Umbria, Marche, and Sardinia follows with a percentage of about 60. The central-south Italian regions have a low percentage of waste disposal, but during the year investigated, they have increased the percentage of waste disposal. As an example, Calabria has reached an increase of 25% in waste disposal in six years, while Lazio and Basilicata reached an increase of 23%. Campania in 2014 exceeded the national percentage of waste disposal (45.2%), and the region is the second of southern Italy, after Sardinia, maintaining this position constant until 2017.

Figure 4 Percentage of waste disposal for each Italian region for the period 2012–2017 (see online version for colours)



Note: Waste disposal percentage on regional base for all years from 2012 to 2017.

2.1.2 *Air quality*

The Regional Agency for Environmental Protection (ARPA) has many air quality monitoring networks throughout Italy. Every day, the Agency collects and processes the data coming from the stations mentioned above following the current regulations. This work focuses on the particulate matter PM_{10} and NO_2 concentrations measured according to the UNI EN 12341:2014 for PM_{10} and UNI EN 14211:2012 for NO_2 from the Italian ARPA network. The data about PM_{10} and NO_2 concentrations were aggregated in the AQI. The AQI is used by government agencies to define the levels of pollutions and to communicate to the population the current levels of pollution. Different countries have their own AQI, defined by their environmental agencies according to different national air quality standards. The MEP (2012) developed its AQI, and Also the US EPA (2011) has developed an AQI that is used to report air quality. In Europe, since 2006, the Common Air Quality Index (CAQI) (European Union, 2012) was used. From 2017 the has launched the European Air Quality Index (EAQI) and suggest to all users to define this index to show the pollution results on websites and other ways for the public information. The AQI used in this work is calculated according to equations (1) and (2). The equations compare the measured PM_{10} and NO_2 concentrations ($C_{PM_{10,m}}$, and $C_{NO_{2,m}}$) with the law limit defined in the 2008/50/CE that is 50 μg/m³ for PM_{10} and 40 μg/m³ for NO_2. $C_{PM_{10,m}}$, and $C_{NO_{2,m}}$ are the annual average concentrations measured by the ARPA network for each region.

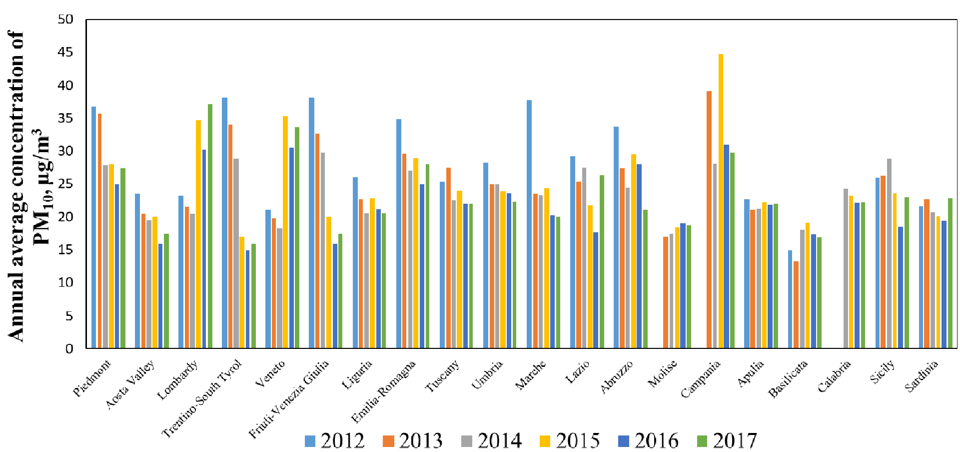
$$AQI_{PM_{10}} = \frac{C_{PM_{10,m}}}{50} * 100 \tag{1}$$

$$AQI_{NO_2} = \frac{C_{NO_{2,m}}}{40} * 100 \tag{2}$$

A low value of the AQI corresponds to a low value of $C_{PM_{10,m}}$ and $C_{NO_{2,m}}$, and so to good air quality. It is possible to obtain an overall AQI where the values of each pollutant AQI are averaged to compute an equivalent AQI.

During 2016, 6% of all the EEA reporting stations were monitored concentrations above the PM_{10} annual limit value. 92% of these stations were located in Turkey (116), Poland (29), the Former Yugoslav Republic of Macedonia (13), and Bulgaria (11). In 2016, the $PM_{2.5}$ concentrations were higher than the annual limit value in four Member States (Poland, Turkey, Bosnia and Herzegovina, and the Former Yugoslav Republic of Macedonia, Bulgaria). The Italian situation in 2016, about PM_{10} levels, is slightly higher (around 30%) than its neighbours like France, Germany, and Austria. However, the Italian average levels of pollution remained constant during the period 2014–2016 (EEA, 2016).

Figure 5 Annual average concentrations (μg/m³) of particulate matter PM_{10} for each Italian region (see online version for colours)



Notes: Annual average concentration of particulate matter PM_{10} measured on a regional base from 2012 to 2017.

Analysing the annual average PM_{10} concentrations (Figure 5) measured by the ARPA networks shows a concentration reduction of PM_{10} from 2012 to 2017 for most of the

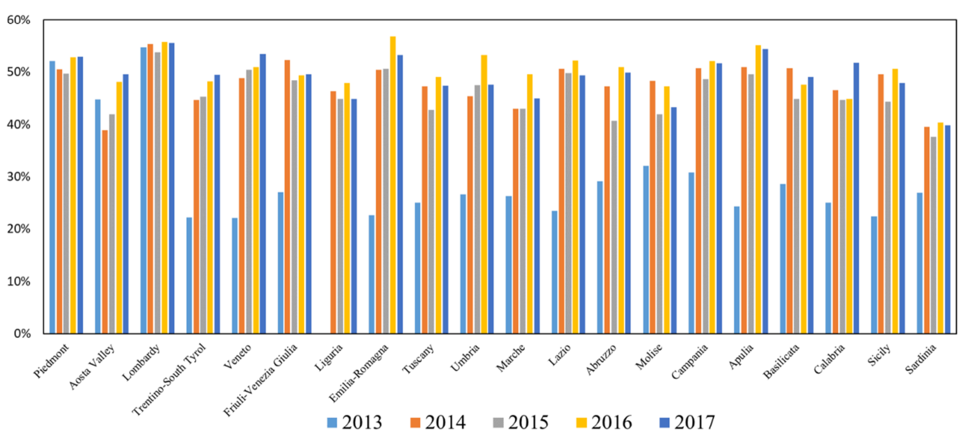
Italian regions. This reduction means that efforts profused by citizens to produce better air quality are improving and are becoming fruitful. On the other hand, in some cases, represented by the most industrialised regions, the pollution is increased during 2016 with respect to 2015 while in 2017, such level remains almost constant. Lazio is one of the rare exceptions because it had an increase in 2017, returning to 2014 levels like Sardinia, which in 2017 had values similar to those of 2013. During 2017 Lombardy had pollution levels higher than its worst year, 2015. This increase is linked to the intense industrialisation and the shape of the Po Valley, which favours the stagnation of particles in the absence of wind (Diémoz et al., 2019).

Figure 5 shows that in 2015 Campania reached a peak in the annual concentration of PM_{10}. In that year, the region was hit by a large number of fires; about 933 fires hit an area of more than 4,700 hectares (data reported by the State Forestry Corps) that most likely mainly influenced the average annual PM_{10} concentration. Aosta Valley, Molise, and Basilicata are small regions with few inhabitants in which the high anthropisation strongly influences the pollution. Despite the growth of mining activity in Basilicata, the data of the annual average are certainly restrained.

2.1.3 Perception of environmental pollution

Every year the National Statistics Institute (ISTAT) broadcast the Italian Statistical Yearbook (ASI), which since 1878, offers a documented portrait of Italian society and its evolutions. The official statistical information produced each year by ISTAT and the Statistical national system is impressive. It embraces all the citizens' principal life relevant issues, the performance of the economy, and the functioning of the institutions. The data about the air pollution perception are obtained by the Italian National Statistical Institute on a sample of 100 peoples of 14 years and having the same characteristics by surveys using an assessment questionnaire of air pollution and its perception.

Figure 6 People of 14 years and more that are worried about environmental problems divided by region (see online version for colours)



During 2013 only people of few regions (Figure 6) were worried about air pollution and such regions were already the most polluted at that time. From 2017 and in particular, in 2015–2016, the people percentage worried about air pollution (Figure 6) increased by 1.8% while during 2017 decreased by 7.13%. This reduction can be attributed to the greater reassurance that citizens are receiving on the environmental theme; in fact, 2017 was the critical year for the development of Italian air quality improvement policies (ISTAT 2018). The spread of environmental concerns, especially those related to the quick way to human action, is also linked to the supply of services and its efficiency level. Moreover, it is related to the greater or lesser presence in the territory of environmental risk determinants, or at least of those factors that are perceived as dangerous and harmful to health by the resident population. The significant problems that near air pollution people are worried about are climate change, electromagnetic pollution, waste management, catastrophe caused by humans, and forest devastation. Thus, the theme of the production and disposal of waste represents a real urgency in Campania, reaching the maximum with 62.5% in 2014, and collects a significant share of people also in Calabria (60.4% in 2014). In particular, in Apulia, from 2015 to 2016, there was an increase in the worries about air quality. In that period, Apulia was involved in the first studies on the particulate matter effect on health. The epidemiological study demonstrated a cause-effect relationship between industrial emissions and the health damage to which the citizens of Taranto, where the largest steel plant in Europe is present, are exposed (Leogrande et al., 2019).

2.2 Data analysis

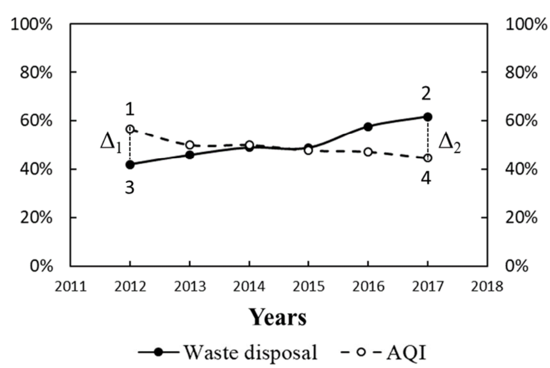
The air quality and waste disposal data were correlated considering the percentage difference of their initial and final value in the period considered calculated according to equations (3) and (4).

$$\Delta_1 = AQI\big|_{2012} - RD\big|_{2012} \tag{3}$$

$$\Delta_2 = RD\big|_{2017} - AQI\big|_{2017} \tag{4}$$

Δ_1 and Δ_2 represent the difference between the AQI and the percentage of waste disposal (RD) evaluated in 2012 and 2017 respectively (Figure 7).

Figure 7 Graphical representation of indexes calculated in equation (3) and (4)



The definition of Δ_1 and Δ_2 as described in equations (3) and (4) represent the optimal environmental situation when the percentage of waste disposal (RD) increases and the AQI decreases with a reduction of air pollution. If both Δ_1 and Δ_2 are greater than zero ($\Delta_1 > 0$, $\Delta_2 > 0$), the AQI curve decrease simultaneously with the RD curve decrease. If

Δ_1 and Δ_2 are lower than zero, the AQI curve decrease simultaneously with the RD curve decrease but the RD values are higher than the AQI ones.

If $\Delta_1 < 0$ and $\Delta_2 > 0$, the percentage of waste disposal (RD) is almost constant in the period considered and the AQI is as lower as higher is Δ_2, with a high or slow reduction of air pollution proportional to its value.

If $\Delta_1 > 0$ and $\Delta_2 < 0$, both AQI and the percentage of waste disposal (RD) are almost constant in the period considered.

For each curve representing the AQI and the RD, the corresponding trend lines were obtained as reported in Figure 3. The resulting curve angular coefficient represents the environmental situation improvement or worsening speed. A negative AQI angular coefficient ac_{AQI} corresponds to an air quality improvement and the greater its absolute value, the faster the air quality has improved. A positive RD angular coefficient ac_{RD} indicates a waste disposal percentage improvement and the greater its value, the faster the improvement has occurred.

3 Results and discussion

The processed data are presented in the form of a graph from which it is possible to show the trends of the analysed variables clearly. The waste disposal percentage was analysed firstly, taking an overview of Italy and subsequently investigating the most interesting regions looking at the detailed waste fraction separated. The behaviour of PM_{10} yearly concentrations was analysed for all the Italian regions and compared with the people's pollution perceptions. The two most interesting regions were compared with the behaviour of PM_{10} and NO_2 concentrations.

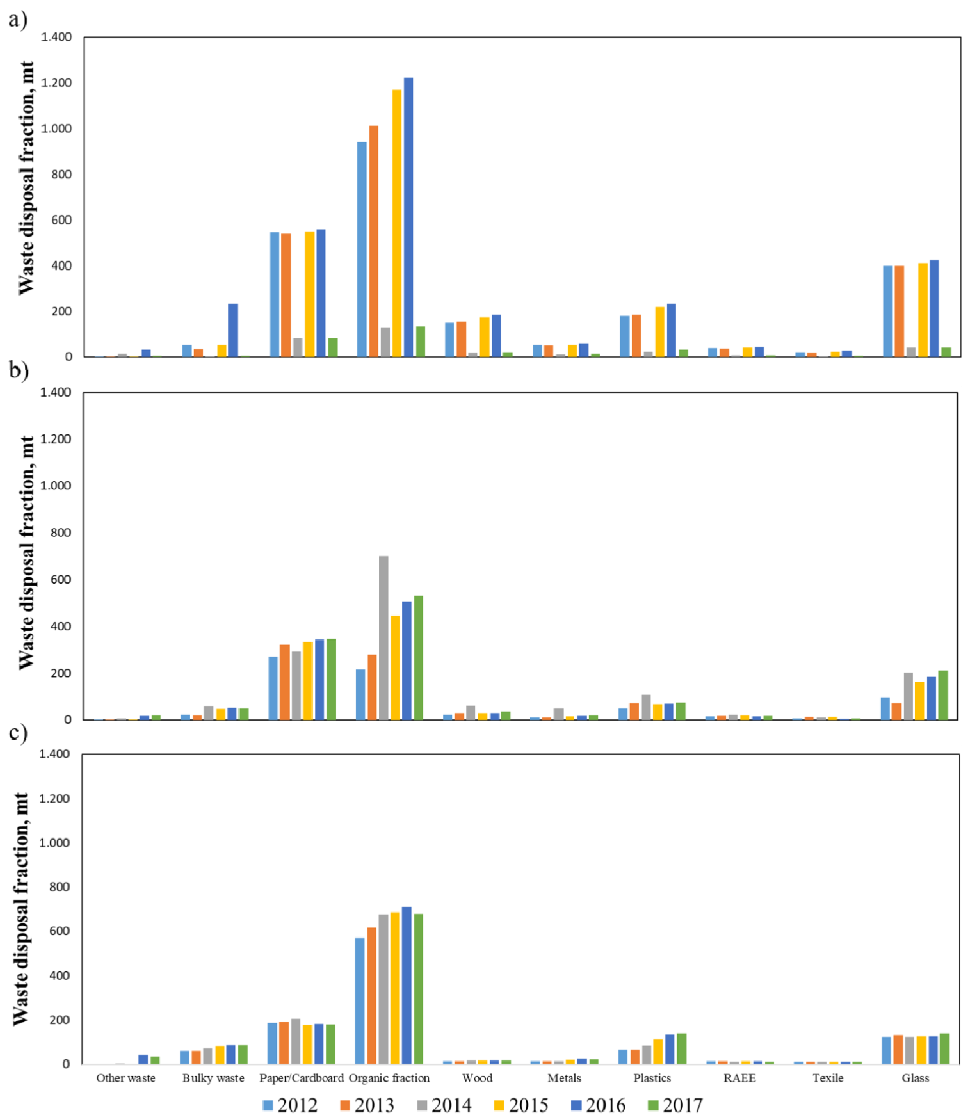
From the analysis, it was possible to highlight an improvement in air quality and the percentage of waste disposal in most Italian regions. Furthermore, by crossing both types of data, it was possible to define which region improved its environmental status faster than the others and quantified this improvement.

3.1 Analysis of waste disposal data of the principal regions

In Italy, waste disposal is represented predominantly by the waste organic fraction and the paper/cardboard fraction that constitute 41.2% and 20.3% of waste weight respectively. The waste disposal also involves glass, plastic, and other types of garbage that represent 11.7%, 7.8%, and 19% of the waste disposal, respectively. The comparison at the regional level of the pro-capita production of urban solid waste and the percentage of each fraction of waste disposal gives interesting information about the waste fraction most separated. For all the regions investigated (Figure 8), the organic, paper, and glass fractions are the most relevant. In particular, in Lombardy [Figure 8(a)], the percentage of that fraction separated is higher than Lazio [Figure 8(b)] and Campania [Figure 8(c)]. Lazio's high separated fraction is a clear result if it is taken into account that Lombardy has about twice the population (almost 10.2 million, source ISTAT 2017) compared to Lazio and Campania. The fractions of waste disposal are homogeneous throughout Italy; from north to south, the highest fraction is the organic one that represents the fraction easily separated by people. In 2017 with 115 kg collected for each inhabitant, Campania is among the regions where the organic fraction is abundant, and in Italy, only five regions have done better (Sardinia, Trentino-Alto Adige, Marche, Veneto, and

Emilia-Romagna). Although the Italian territory is different, the composition of waste disposal is similar. The fractions that are more separated are those that are more easily recognisable and that have a more consolidated separation mechanism.

Figure 8 Fractions of waste disposal in, (a) Lombardy (b) Lazio (c) Campania during 2012–2017 (see online version for colours)

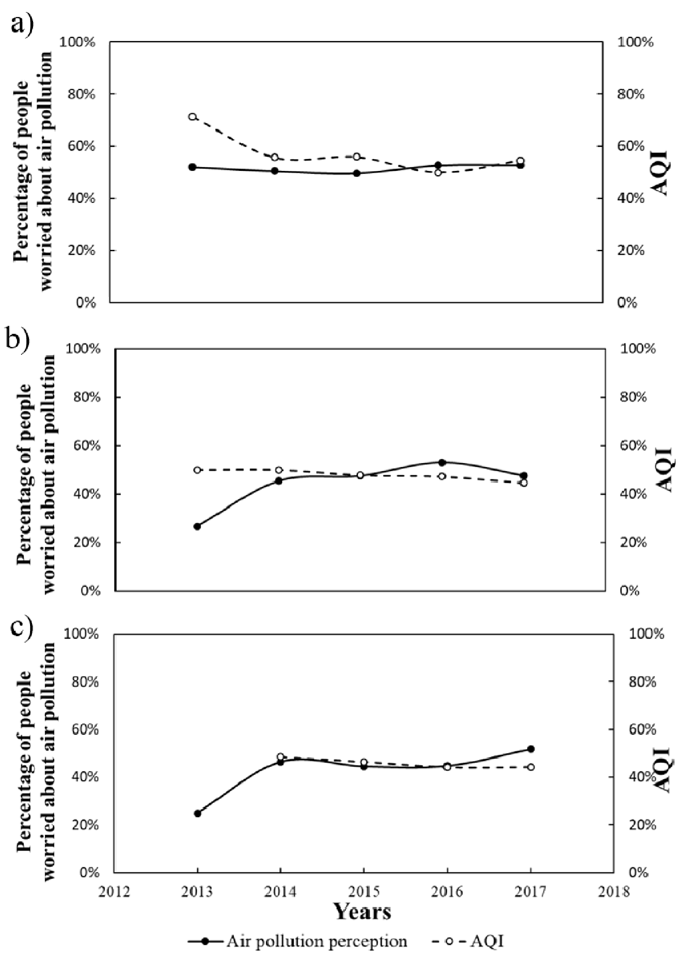


Notes: Million tonnes of waste fraction collected on a regional base for each fraction of waste disposal from 2012 to 2017. The waste fractions are bulky waste, paper/cardboard, organic, wood, metals, plastics, RAEE, textile, glass and other waste.

3.2 Comparison between air quality data and its perception

Between 2013 and 2017, a large percentage of the Piedmont population [Figure 9(a)], Umbria [Figure 9(b)], and Calabria [Figure 9(c)] had the perception of a highly polluted city. From these three regions' AQI values (Figure 9) is clear that during 2013–2017 the PM_{10} pollution is decreased with a decrease of the AQI. Both in the north and the centre and the south, taking some regions as an example (Figure 9), it is possible to see that in the various points of Italy, there are similar situations to be attributed to different environmental policies that make the regions more or less virtuous. For example, in Umbria and Calabria, the low population and low industrialisation have positively influenced the air quality.

Figure 9 People worried about air quality and $AQI_{PM_{10}}$ in 2012–2017, (a) Piedmont (b) Umbria (c) Calabria

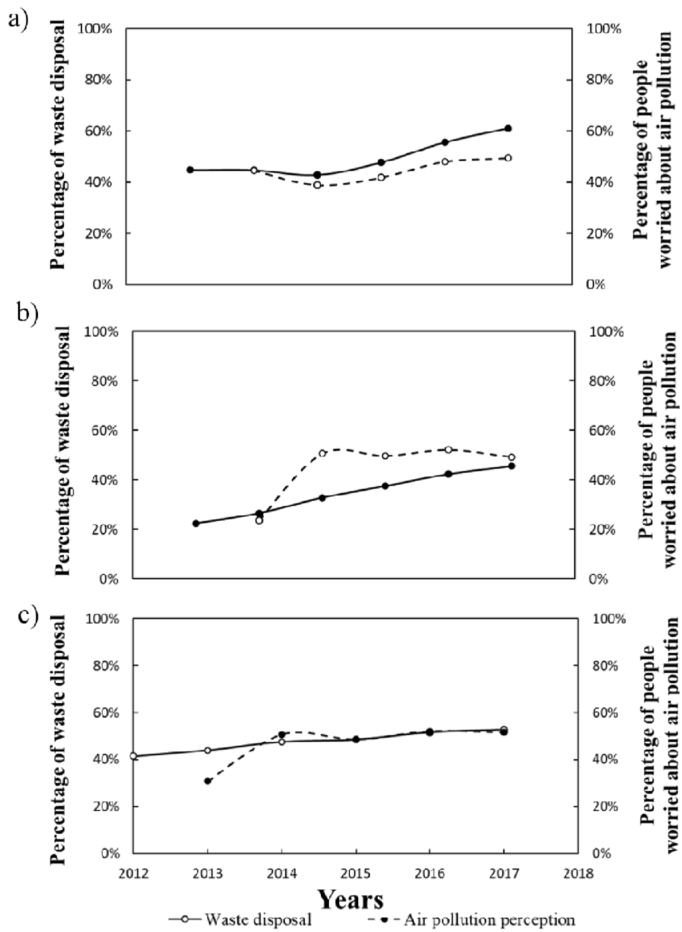


Notes: Percentage of people worried about air quality (black solid line) and AQI (black dashed line) for three most interesting Italian regions from 2012 to 2017.

3.3 Comparison between waste disposal data and people's pollution perception

The increase in Italians' concern for environmental quality in the years 2013–2017 has led to an increase in the percentage of waste disposal collected by citizens. In particular, among the most interesting Italian regions, there are Aosta Valley [Figure 10(a)], Lazio [Figure 10(b)], and Campania [Figure 10(c)] from which is clear that the interest in the environment is increased during the years. The more people are concerned about environmental quality, the more the citizen's sensitivity grows. This statement is based on the analysis of Figure 10, where it is clear that air quality and waste disposal increased during the period considered. Throughout Italy, there is a general increase in the percentage of people interested in air quality. In Campania, the effect is constant due to the strict environmental management plans.

Figure 10 People worried about air quality and waste disposal, (a) Aosta Valley (b) Lazio (c) Campania



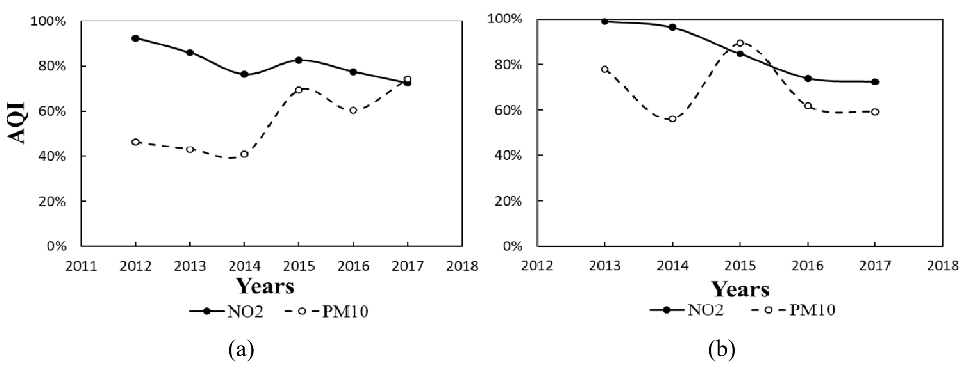
Notes: Percentage of waste disposal (solid black line) and air pollution perception (black dashed line) for three most interesting Italian regions from 2012 to 2017.

3.4 Comparison between PM_{10} and NO_2 data

Figure 11 shows the level of AQI_{NO_2} of the two Italian regions with the highest $AQI_{PM_{10}}$. In both Lombardy and Campania, while the AQI_{NO_2} decrease, the $AQI_{PM_{10}}$ increases meaning an improvement of NO_2 concentrations and worsening PM_{10} levels. The decrease in NO_2 is attributable to the technological innovation of diesel cars. From 2013 to 2014, the gasoline car share decreased further, from 55.5 to 54.1%, to those of diesel (37.9%) and gas (7.7%) while electric cars increased (+3%). Subsequently, in the years 2015–2017, the types of vehicles circulating on the Italian territory have gradually changed. The primary source of data is the public automotive register (ACI), which reports that especially in the years 2015–2017, the number of Euro 5 and Euro 6 cars increases (34.5% of the total, 29.7% in 2016). Low-emission cars also increased (+8.4% on 2016 for gas/bi-fuel cars, +36.4% for electric/hybrid cars), whose share is close to 10% (8.5% gas/bi-fuel, 0.7% electric/hybrid). However, the share of eldest and most polluting cars (eight years and up) continues to grow, accounting for 63.4% (62.5% in 2016).

Besides, the PM_{10} formation is also due to the moving parts wear and tear of moving as brake wear while NO_2 is formed predominantly by combustion. The reduction of NO_2 concentrations can also be attributable to the improvement in domestic heating technology. In the last year, Italian environmental policies promoted the purchase of new generation heating systems with low emissions.

Figure 11 AQI_{NO_2} and $AQI_{PM_{10}}$ for, (a) Lombardy (b) Campania



Notes: AQI for NO_2 (black solid line) and AQI for PM_{10} (black dashed line) for two most interesting Italian regions from 2012 to 2017.

3.5 Comparison between AQI and waste disposal data

Comparing the ac_{AQI} of all Italian regions reported in Table 2, it is clear that Trentino South-Tyrol and Friuli-Venezia Giulia are the regions that improved the air quality with the highest reduction in PM_{10} concentration in the period 2012–2017. The lowest value of ac_{AQI} corresponds to Sardinia, where the AQI decreased very slowly in the six years considered.

Moreover, the values of ac_{AQI} (Table 2), 75% of the Italian regions have a negative angular coefficient with a consequent improvement of the AQI. The remaining 25% of the regions are the most industrialised such as Lombardy (high number of industrial poles), Veneto (high presence of fuel plant as the Eni in Porto Marghera), and Apulia (with the largest steel plant in Europe – ILVA).

The values of Δ_1 and Δ_2 (Table 2) are both positive only for 11 regions as Piedmont, Aosta Valley, Trentino-South Tyrol, Friuli-Venezia Giulia, Liguria, Emilia Romagna, Tuscany, Umbria, Marche, Abruzzo, and Basilicata. These regions are the ones that improved air quality by about 40% and the waste disposal in the range of 10–20%. For only two regions $\Delta_1 < 0$ and $\Delta_2 > 0$, the percentage of waste disposal is almost constant and the air quality improves. In particular, among these regions, Veneto is the one with the highest Δ_2, so the one that improves higher the AQI. Only for three regions, Lazio, Apulia, and Sicily $\Delta_1 > 0$ and $\Delta_2 < 0$ with negative ac_{AQI} values meaning a slow improvement of the AQI. The values of Δ_1 and Δ_2 are both negative for Lombardy, Molise, Campania, and Calabria. In these regions, both the AQI and RD improves RD values are higher than AQI ones.

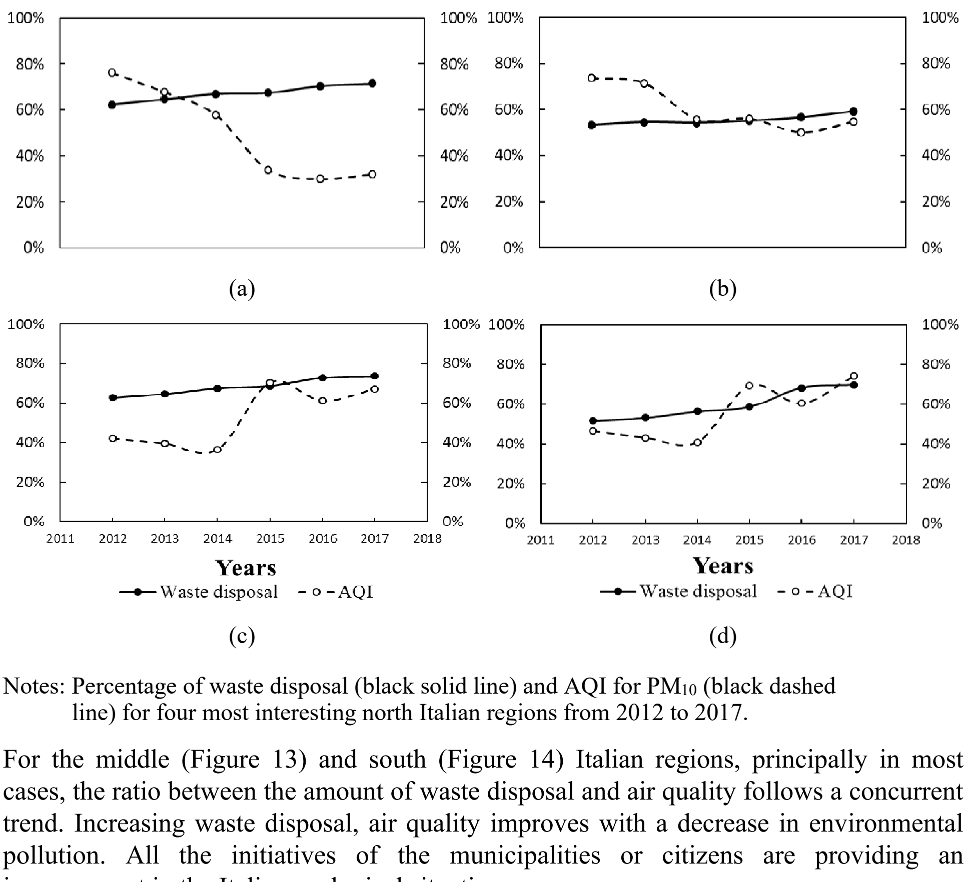
According to the positive ac_{RD} values reported in Table 2, all regions improve the percentage of waste disposal. Among the regions, Calabria, Lazio, and Apulia are the regions that have the highest ac_{RD}. In particular, Lazio and Apulia, as said above, are the ones with the $\Delta_1 > 0$ and $\Delta_2 < 0$. This condition means that the waste disposal percentage improves with higher respect to the AQI.

Table 2 Indexes obtained for each region calculated as described in Subsection 2.2

Region	*Δ_1, %*	*Δ_2, %*	*ac_{AQI}, [y^{-1}]*	*ac_{RD}, [y^{-1}]*
Piedmont	20.3	4.6	–4.5	1.1
Aosta Valley	2.2	26.1	–2.6	3.4
Lombardy	–5.4	–4.6	6.3	3.9
Trentino-South Tyrol	14.0	39.6	–10.2	1.8
Veneto	–20.5	6.4	6.4	2.3
Friuli-Venezia Giulia	18.7	30.5	–9.3	1.9
Liguria	21.1	7.6	–1.7	3.7
Emilia-Romagna	19.0	7.8	–2.6	2.6
Tuscany	10.8	9.9	–1.8	2.8
Umbria	14.5	17.1	–2.0	3.8
Marche	24.5	23.3	–5.5	2.1
Lazio	36.1	–7.3	–2.5	4.8
Abruzzo	29.4	13.8	–3.2	3.6
Molise	–18.4	–6.8	1.0	2.6
Campania	–41.5	–6.6	–3.2	2.3
Apulia	27.9	–3.6	1.2	4.4
Basilicata	8.1	11.6	1.3	1.3
Calabria	–14.6	–4.7	–1.5	5.3
Sicily	38.5	–24.3	–2.4	1.4
Sardinia	–5.2	17.4	–0.3	3.0

In northern Italy (Figure 12), with the same geographical area, the effect of the worsening of air quality is due to the massive industrialisation that affects air quality. In Trentino-South Tyrol, the air quality improves by 40%, and at the same time, there is an increase in the waste disposal of 10%. Veneto and Lombardy [Figures 12(c) and 12(d)] reach a constant AQI of 20% that in Veneto undergoes a slight improvement since 2016. In Lombardy, the AQI worsens until it doubles in 2012 despite an improvement in the waste collection of 20%. This growth is indicative of the strong influence of the industrial factories and of the high amount of vehicles that each day transit along with Lombardy and Veneto.

Figure 12 Waste disposal and $AQI_{PM_{10}}$ during 2012–2017, (a) Trentino-South Tyrol (b) Piedmont (c) Veneto (d) Lombardy

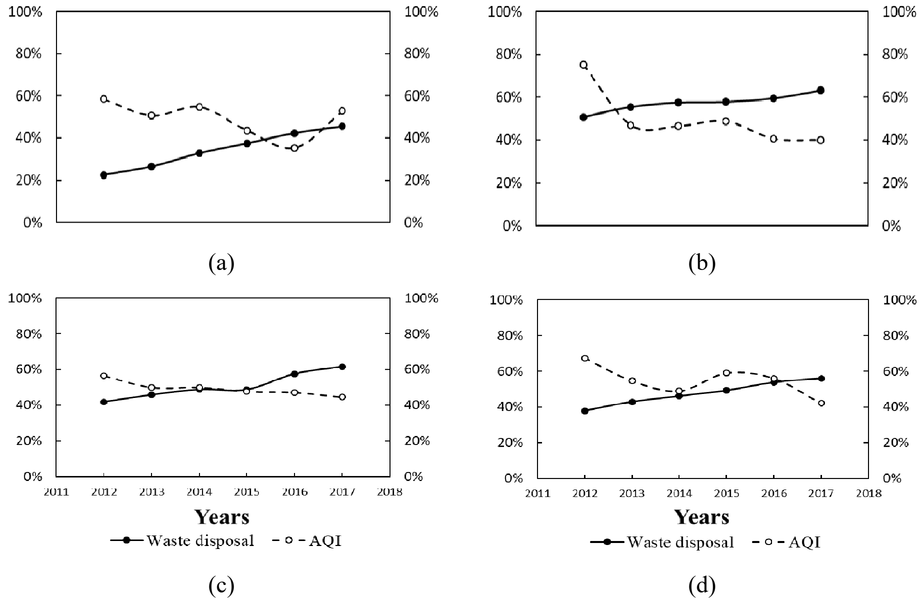


Notes: Percentage of waste disposal (black solid line) and AQI for PM_{10} (black dashed line) for four most interesting north Italian regions from 2012 to 2017.

For the middle (Figure 13) and south (Figure 14) Italian regions, principally in most cases, the ratio between the amount of waste disposal and air quality follows a concurrent trend. Increasing waste disposal, air quality improves with a decrease in environmental pollution. All the initiatives of the municipalities or citizens are providing an improvement in the Italian ecological situation.

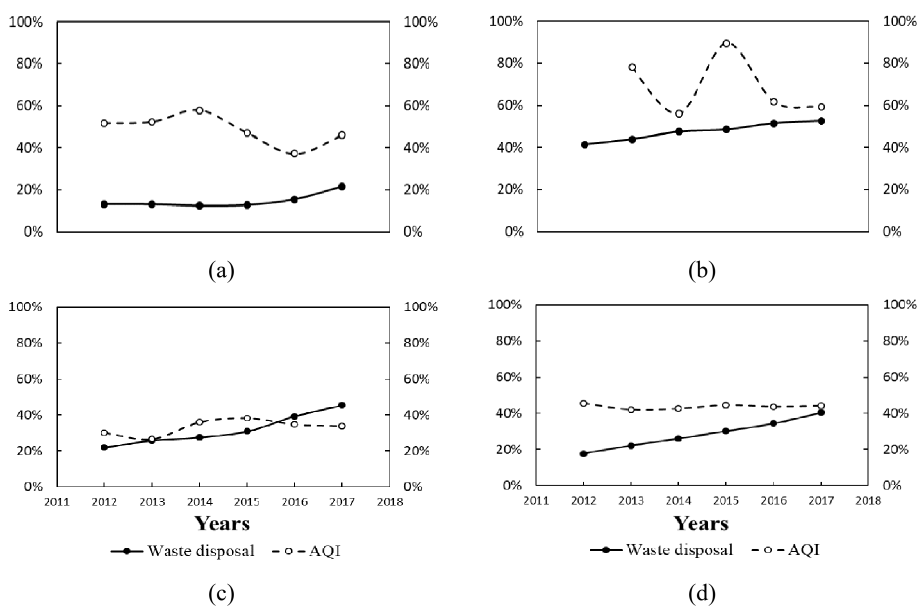
In Marche and Abruzzo [Figures 13(b) and 13(c)], the AQI improves about 40% in six years. In Lazio [Figure 13(a)], the AQI decreases about 25% until 2016 while it has a worsening in 2017 to the levels of 2012. In all the regions of middle Italy, the waste disposal increase in six years by about 20%.

Figure 13 Waste disposal and $AQI_{PM_{10}}$ during 2012–2017, (a) Lazio (b) Marche (c) Umbria (d) Abruzzo



Notes: Percentage of waste disposal (black solid line) and AQI for PM_{10} (black dashed line) for four most interesting north Italian regions from 2012 to 2017.

Figure 14 Waste disposal and $AQI_{PM_{10}}$ during 2012–2017, (a) Sicilia (b) Campania (c) Basilicata (d) Apulia



Notes: Percentage of waste disposal (black solid line) and AQI for PM_{10} (black dashed line) for four most interesting north Italian regions from 2012 to 2017.

In Apulia, the AQI is almost constant at 41% during 2012–2017, with an increase in waste disposal by about 20%. In all the southern-Italy regions except Sicily, the waste disposal increase by 20% in six years.

4 Conclusions

The data analysed show a significant improvement in the percentage of waste disposal in the years 2012–2017 for all the Italian regions. During 2012–2017 the air quality in Italy is improved in most of the regions.

Among the Italian regions, Calabria is the one with the lowest percentage of waste disposal, but at the same time, it is the one that in 2012–2017 has improved more rapidly, and in 2017 it reached 25% more than 2012.

From the analysis, it is clear that most of the waste disposal involves organic fraction, paper, and similar glass in all regions of Italy.

The perception of pollution regardless of the geographical area and the conditions of the environmental matrix is increasing in all regions, in particular among the regions most concerned there is the Emilia Romagna, which, together with Lombardy, shows the highest level of concern for air quality.

From north to south, in all the regions of Italy, as the interest in the environment increases, waste disposal increases, bearing witness to the citizen's desire to improve the environment in which they live.

The data analysis shows clearly that for most of the regions investigated when the waste disposal increase also the air quality increase. This increase can be explained, also considering the level of people's pollution perception. Higher is the pollution perception, and higher is the waste disposal percentage, and better is the air quality. The worried citizen works to improve its environmental state.

The information deriving from the air quality measures can be useful tools for decision support for all public administrations. As an example, the dispersion and forecasting models on air quality elaborated by the regional agencies, allow the identification of critical days for pollution. A day when the AQI is expected to be high, an agency or a public health organisation could advise sensitive groups such as the elderly, children, and people with respiratory problems or cardiovascular, to avoid efforts or physical activity outdoors. During an awful air quality period, such as a pollution peak, the AQI indicates that acute exposure can cause significant damage to public health. In this case, the competent authorities can invoke contingency plans and block relevant polluting sources such as some types of plants until the dangerous levels decrease.

From the results obtained, it is clear that the combination of policies for improving air quality and waste disposal has led to an improvement in the Italian environmental matrix. These policies must undoubtedly be enhanced to ensure further growth of the ecological status.

References

Acikgoz, A., Baykara, B., Camsari, U.M., Ellidokuz, H. and Uysal, N. (2013) 'Preliminary investigation of association between indoor air quality and emergence of depressive symptoms', *Sustainable Environmental Research*, Vol. 23, No. 6, pp.385–391.

Cascio, W.E. (2016) 'Proposed pathophysiologic framework to explain some excess cardiovascular death associated with ambient air particle pollution: insights for public health translation', *Biochimica et Biophysica Acta*, Vol. 1860, No. 12, pp.2869–2879.

Cassee, F., Héroux, M., Gerlofs-Nijland, M. and Kelly, F. (2013) 'Particulate matter beyond mass: recent health evidence on the role of fractions, chemical constituents and sources of emission', *Inhalation Toxicology*, Vol. 25, No. 14, pp.802–812.

Catalano, M., Galatioto, F., Bell, M., Namdeo, A. and Bergantino, A.S. (2016) 'Improving the prediction of air pollution peak episodes generated by urban transport networks', *Environmental Science & Policy*, Vol. 60, pp.69–83.

Centrone, G. and Coslovich, L. (2008) 'Social responsibility and sustainability in motorway corporate governance', *International Journal of Environment and Sustainable Development*, Vol. 7, No. 1, pp.94–113.

Diémoz, H., Barnaba, F., Magri, T., Pession, G., Dionisi, D., Pittavino, S., Tombolato, I.K.F., Campanelli, M., Della Ceca, L.S., Hervo, M., Di Liberto, L., Ferrero, L. and Gobbi, G.P. (2019) 'Transport of Po Valley aerosol pollution to the northwestern Alps – part 1: phenomenology', *Atmospheric Chemistry and Physics*, Vol. 19, pp.3065–3095.

European Environment Agency (EEA) (2016) *European Air Quality Index: Current Air Quality Information at your Fingertips*.

European Union (2012) *CAQI Air Quality Index – Comparing Urban Air Quality*.

Giovanis, E. (2015) 'Relationship between recycling rate and air pollution: waste management in the State of Massachusetts', *Waste Management*, Vol. 40, pp.192–203.

Giuliano, A., De Bari, I., Motola, V., Pierro, N., Giocoli, A. and Barletta, D. (2019a) 'Techno-environmental assessment of two biorefinery systems to valorize the residual lignocellulosic biomass of the Basilicata Region', *Mathematical Modelling of Engineering Problems*, Vol. 6, No. 3, pp.317–323.

Giuliano, A., Catizzone, E., Barisano, D., Nanna, F., Villone, A., De Bari, I., Cornacchia, G. and Braccio, G. (2019b) 'Towards methanol economy: a techno-environmental assessment for a bio-methanol OFMSW/biomass/carbon capture-based integrated plant', *International Journal of Heat and Technology*, Vol. 37, No. 3, pp.665–674.

Giuliano, A., Gioiella, F., Sofia, D. and Lotrecchiano, N. (2018) 'A novel methodology and technology to promote the social acceptance of biomass power plants avoiding NIMBY syndrome', *Chemical Engineering Transactions*, Vol. 67, pp.307–312.

Guariso, G., Maione, M. and Volta, M. (2016) 'A decision framework for integrated assessment modelling of air quality at regional and local scale', *Environmental & Science Policy*, Vol. 65, No. C, pp.3–12.

Isprambiente.it (2018) *Waste Cadastre Official Website* [online] https://www.catasto-rifiuti.isprambiente.it/ (accessed March 2019).

Lang, J.C. (2005) 'Zero landfill, zero waste: the greening of industry in Singapore', *International Journal of Environment and Sustainable Development*, Vol. 4, No. 3, pp.331–351.

Leogrande, S., Alessandrini, E.R., Stafoggia, M., Morabito, A., Nocioni, A., Ancona, C., Bisceglia, L., Mataloni, F., Giua, R., Mincuzzi, A., Minerba, S., Spagnolo, S., Pastore, T., Tanzarella, A., Assennato, G., Forastiere, F. and CSA Puglia Study Group (2019) 'Industrial air pollution and mortality in the Taranto area, Southern Italy: a difference-in-differences approach', *Environment International*, Vol. 132, 105030.

Ministry of Environmental Protection of the People's Republic of China (MEP) (2012) *Technical Regulation on Ambient Air Quality Index*.

Miranda, A.I., Relvas, H., Viaene, P., Janssen, S., Brasseur, O., Carnevale, C., Declerck, P., Maffeis, G., Turrini, E. and Volta, M. (2016) 'Applying integrated assessment methodologies to air quality plans: two European cases', *Environmental Science & Policy*, Vol. 65, pp.29–38.

Morejon, C.F.M. (2012) 'New model of municipal solid waste management', *International Journal of Environment and Sustainable Development*, Vol. 11, No. 3.

Nathan, H.S.K. and Reddy, S.B. (2012) 'Urban transport sustainability indicators – application of multi-view black-box (MVBB) framework', *International Journal of Environment and Sustainable Development*, Vol. 12, No. 3.

Sharma, S., Panwar, T.S., Chatani, S. and Kwatra, S. (2014) 'Modelling NO_2 concentrations using MM5-CMAQ modelling system', *Sustainable Environmental Research*, Vol. 24, No. 2, pp.93–105.

Slovic, A.D. and Ribeiro, H. (2018) 'Policy instruments surrounding urban air quality: the cases of São Paulo, New York City and Paris', *Environmental Science & Policy*, Vol. 81, pp.1–9.

Sofia, D., Gioella, F., Lotrecchiano, N. and Giuliano, A. (2020b) 'Cost-benefit analysis to support decarbonization scenario for 2030: a case study in Italy', *Energy Policy*, Vol. 37.

Sofia, D., Gioiella, F., Lotrecchiano, N. and Giuliano, A. (2020a) 'Mitigation strategies for reducing air pollution', *Environmental Science and Pollution Research*.

Sofia, D., Giuliano, A. and Gioiella, F. (2018a) 'Air quality monitoring network for tracking pollutants: the case study of Salerno city center', *Chemical Engineering Transactions*, Vol. 68, pp.67–72.

Sofia, D., Giuliano, A., Gioiella, F., Barletta, D. and Poletto, M. (2018b) 'Modeling of an air quality monitoring network with high space-time resolution', in Friedl, A., Klemeš, J.J., Radl, S., Varbanov, P.S. and Wallek, T. (Eds.): *Computer Aided Chemical Engineering*, Vol. 43, pp.193–198.

Talaiekhozani, A., Bagheri, M., Najafabadi, N.R. and Borna, E. (2016) 'Effect of nearly one hundred percent of municipal waste recycling in Najafsbad City on improving its air quality', *Journal of Air Pollution and Health*, Vol. 24, No. 2, pp.93–105.

United States Environmental Protection Agency (US EPA) (2011) *Air Quality Index (AQI) – A Guide to Air Quality and Your Health*.

Valeri, E., Gatta, V., Teobaldelli, D., Polidori, P., Barratt, B., Fuzzi, S., Kazepov, Y., Sergi, V., Williams, M. and Maione, M. (2016) 'Modelling individual preferences for environmental policy drivers: empirical evidence of Italian lifestyle changes using a latent class approach', *Environmental Science & Policy*, Vol. 65, pp.65–74.