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WP3.6 WASTE

2ND PASS ASSESSMENT REPORT

INTEGRATED ENVIRONMENTAL AND HEALTH IMPACT ASSESSMENT OF WASTE MANAGEMENT IN LAZIO (ITALY)

NOVEMBER, 2010

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Integrated environmental and health impact assessment of waste management in Lazio (Italy)

Executive Summary

Introduction The potential environmental and health effects of waste management of municipal solid waste (MSW) are poorly understood, especially when the different aspects of the full chain process (waste production, collection, transport, recycling, treatment, disposal) are taken into consideration.

A prognostic assessment was carried out in Lazio (a region in Central Italy with about 5.5 million inhabitants including Rome) by comparing two future waste management scenarios based on appropriate sustainable measures to the baseline situation representing the business as usual situation. We evaluated the 2008 baseline scenario (BS) and two alternative 2016 scenarios, Waste Strategy (WS) and Green Policy (GP). In the first alternative scenario (WS), waste management was modified because of an increase in recycling/composting, different waste flows, cleaner transportation, new management plants and no landfilling without pre-treatment. In the second alternative scenario (GP), an additional drastic reduction in the total amount of waste was foreseen together with a very high recycling rate.

Methods The population under evaluation were residents in Lazio, and, in particular, people living in Rome potentially exposed to exhaust fumes from waste collection and transport. We also considered the population living close to Mechanical and Biological Treatment (MBT) plants (200 meters), landfills (2 km) and incinerators (3 km) as well as workers in the waste industry for the risk of occupational accidents. Pollutants from transport, emissions from incineration, and combustion of landfills biogas were evaluated. Concentrations of specific pollutants (PM_{10} and NO_2) were modelled using ad hoc GIS models and the ADMS-Urban model. Population-weighted exposure levels were calculated. Concentration-response functions were derived from systematic reviews of the literature. Cases of specific diseases and disorders attributable to waste management (incidence of cancer, newborns of low-birth weight, congenital anomalies, and prevalence of respiratory disorders and odour annoyance), Years of Life Lost (YLL), and Disability Adjusted Life Years (DALYs) were estimated for the 35-year period from 2016 to 2050.

Results

<u>Waste management and emissions.</u> At the baseline the total volume of waste produced was 3.330 mTonnes, of which 0.593 was recycled/composed, 1.902 was landfilled without pre-treatment, and 0.835 was managed with Mechanical and Biological Treatment (with production of Refuse Derived Fuels (RDFs) for incineration). Under the Waste strategy, the recycling/composting rate will be increased up to 60% and no landfill will be in use without pre-treatment. Under the Green policy, the amount of waste production will decrease to 15% and recycling/composting rate will increase to 70%. A considerable decrease (up to 90%) will be seen for most of the emitted pollutants (for instance particulate matter (PM) emissions will go from 17.9 to 6.6 and 4.13 tonnes/year for the three scenarios, respectively)

<u>Population.</u> A total of 36,191 people were living nearby MSW facilities at baseline (23,917 close to the two incinerators, 2,345 close to MBTs, and 9,929 close to landfills). With the Waste strategy, the number of people living close to plants will increase to 51,639 subjects, mainly due to the introduction of new incinerators (from 23,917 to 39,284 subjects). On the other hand, the Green policy will decrease to 14,606 the population involved with an important reduction of people residents close to incinerators and landfills. Important differences by socioeconomic status were present at baseline, with people of lower socioeconomic status being relatively more exposed to waste management than more affluent people. In addition to the general population, waste workers were estimated: about 10,000 for the baseline and the Waste strategy whereas the number will decrease to about 8,300 workers under the Green Strategy.

<u>Pollution from transport and management plants.</u> At baseline, a total of 18,916 journeys of trucks per year were necessary in Rome for the transfer of waste from the resident areas to the management facilities. Under the baseline scenario, about 10 millions Kilometers per year were travelled. In the Waste strategy, the number of journeys and the kilometers travelled are

reduced of 37.2% and 38.2%, respectively. The reduction was even more radical in the Green policy scenario, with a reduction of 65.3% in journeys and 64.5% in kilometers travelled. The contribution of waste transport to the average annual concentration of NO_2 in Rome was 0.0199 $\mu g/m^3$ at baseline, 0.00198 $\mu g/m^3$ with waste strategy and 0.00118 $\mu g/m^3$ with the green policy with an important reduction of the population weighted exposure (-90%, -95 %, respectively). Estimated annual average concentrations of air pollutants emitted from the plants in the vicinity of landfills and incineration plants were rather small. The population weighted NO_2 (and PM_{10}) exposure levels were also relatively low, ranging from 0.05 to 0.7 $\mu g/m^3$for landfills and 0.03 to 0.06 $\mu g/m^3$ for incinerators.

Attributable cases. An annual frequency of 243 occupational injuries in the waste sector was estimated, with 0.8 fatalities each year; the absolute number of accidents will decrease in the Green Policy because of the reduction of the manpower. The impact of transport of waste on the population of Rome could be estimated in 561 (related to NO_2 exposure) and 14 (related to PM exposure) Years of Life Lost (YLL) at baseline; the impact as YLLs decreases to 50 and 1 (Waste strategy) and to 29 and 0 (Green policy), respectively. For MBTs,_the prevalence of subjects with severe odours annoyance (about 130 subjects) and the prevalence of people with respiratory symptoms attributable to the plants (about 500 subjects) was constant in all the scenarios. For incinerators, the cumulative incidence of attributable cancer cases over the 35 year period was 7.5, 11.7and 2.5 in the three scenarios, respectively. A total of 10 YLL (NO_2) attributable to incinerators were estimated at baseline. The number increased to 15.9 YLL with the waste strategy and decreased to 9.6 with the green policy. The YLL attributable to PM were very small. For landfills, low birth weight cumulative incidence was 8.3 newborns (baseline and waste strategy) and 2.8 in the green policy. The cumulative incidence of congenital anomalies was of 0.3 subject (baseline and waste strategy) and 0.1 for the green policy. The health impact of landfills as YLL was 17.9 (NO_2) estimated at baseline and with waste strategy and a decrease to 12.4 with the green policy. The prevalence of severe odours annoyance and respiratory symptoms assessed for residents at 200 meters from the landfills, were the same (54 and 424, respectively) at the baseline and with the waste strategy while a decrease to 19 and 147 were predicted with the green policy.

DALYS. The most important health impact of waste management was occupational accidents, responsible of about 40,000 DALYs for the baseline and the Waste strategy while the impact decreases to 33,000 DALYs with the Green policy. For the general population, a total of about 3000, 2500, and 1600 DALYs were estimated under the different scenarios, respectively. The largest contribution to DALYs for the general population was from respiratory symptoms (about 90%) and odour annoyance; the contribution from the other health disorders was small.

Conclusion The environmental health impact of waste management was moderate when compared to other potential environmental factors. Few aspects should be underlined: 1. the most important heath impact of waste management is occupational accidents related to the collection, load and transport of waste. 2. the possible role of transport of waste with highly polluting trucks is often neglected in the discussion of waste management related health problems. 3. a relevant health impact was estimated from landfills and MBTs with regards to respiratory symptoms and odour annoyance. This is not surprising as the perception of these aspects is the basis for community concerns over waste management plants. 4. the environmental and health impact generated from traditional management plants like landfills and incinerators is limited due to the strict legislation on emissions. 5. significant improvement in the environmental and health impacts can be achieved with future strategies dedicated to waste reduction, recycling, clean transport, composting and waste treatment before the final destination. However, our findings suggest an important equity issue as there is a differential distribution by social class for people living close to management plants. The same happens for occupational injuries among workers. Since the equity issue is not solved in relative terms even in the most radical Green strategy, more attention should be posed to this aspect in waste management planning and operation.

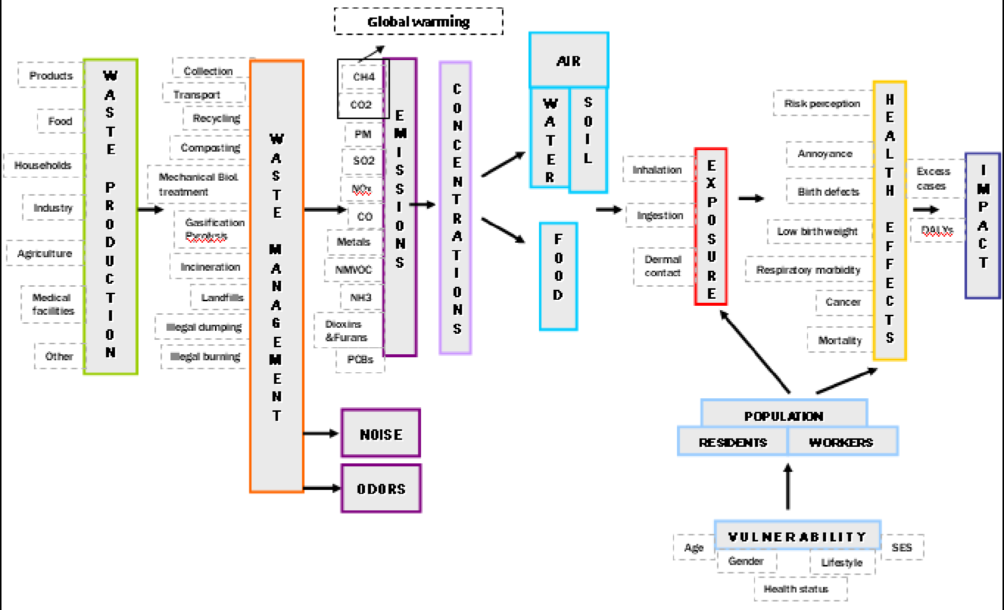
WASTE ASSESSMENT REPORT	
Title	**Integrated environmental and health impact assessment of waste management in Lazio (Italy)**

Scope and content

Description

Management of municipal solid waste (MSW) can be a significant source of environmental contamination and thus of human exposure to pollutants, especially for those living in close proximity to management plants (i.e. incinerators and landfills). Exposures may also occur more widely as a result of collection and transportation of waste using heavy duty diesel vehicles. The health impact of some exposures has been evaluated in epidemiological studies with controversial results (Porta et al, 2009). In addition, workers may suffer from occupational injuries during the collection and transportation phases, the general population may be annoyed from odours and concerns about health effects may cause environmental worry.

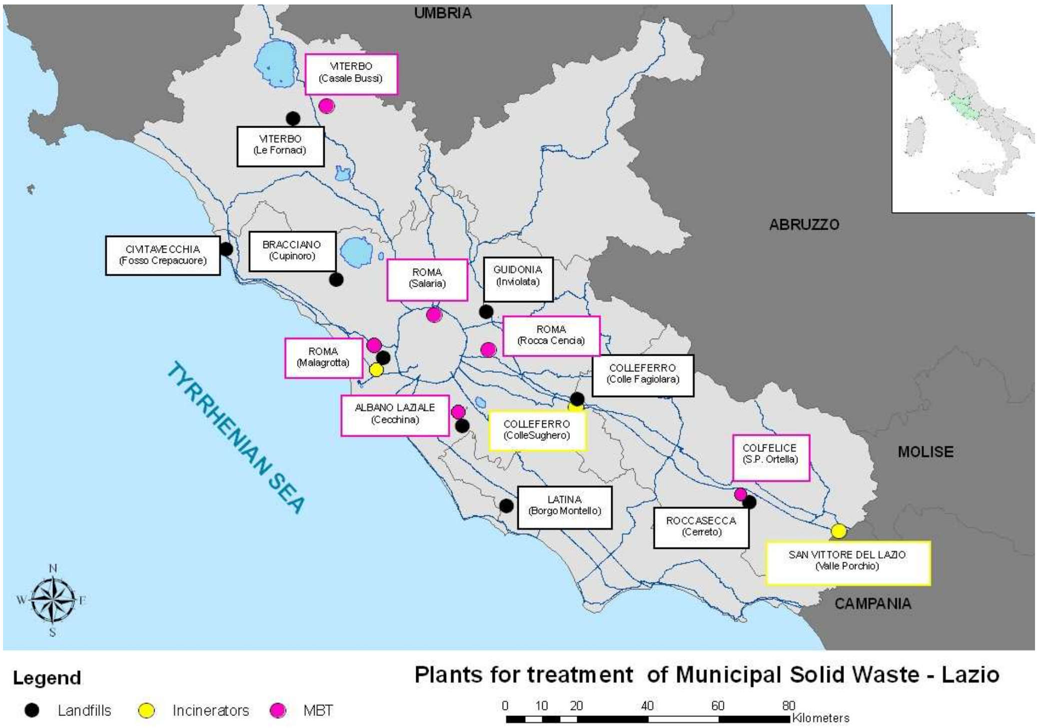
Figure 1. The full chain approach - from waste production to health effects



Several additional aspects complicate the issue, including compliance with new EU legislation (aimed at waste reduction, reuse, recycling, and landfills closure), conflicting interests of the stakeholders and communities concerns. In the European Union, we can expect substantial changes in the coming years, as government policies need to change and industry and communities will most certainly face new economic circumstances and environmental conditions. Future changes in waste management may therefore have significant implications for human exposure and health, and may raise public anxiety. The key question remain, namely what are the environmental and health impacts for the general population of changes in waste management systems in the European Union over the foreseeable future.

	The overall aim of this case study was to assess potential exposures and health effects arising from MSW throughout their lifecycle, from collection to disposal or treatment under different scenarios. Following the methods and the lessons learned in the diagnostic assessment for the year 2001 performed in the three countries (Italy, England and Slovakia) INTARESE study (Forastiere et al, 2009), we have conducted a prognostic assessment in the Lazio region of Italy (about five million inhabitants including the city of Rome). In our assessment model, we evaluated the environmental and health impact of different policies for MSW, considering a baseline scenario for the year 2008 and two alternative scenarios for 2016. In our assessment we evaluate MSW collection and transport, mechanical and biological treatment (MBT) and incineration plants and landfills. In this integrated assessment, different exposures and health effects were under considerations including pollutants from transport, emissions from incineration and combustion of landfills biogas, and occupational injuries. Annex 1: Waste causal diagram
Type of assessment	A <u>prognostic assessment</u> was carried out by comparing two future waste management scenarios based on appropriate sustainable measure to the baseline situation representing the business as usual situation. The alternative scenarios were based on the assumption that <u>prescriptive norms</u> will change the situation with regards to waste production, collection, transportation, treatment and disposal. The assessment considered the downstream impacts of these norms and conditions on exposure and health, but did not consider how the conditions would be achieved (e.g. what technological or socio-economic changes would be necessary and their costs), nor the implications of these changes. We focused only on the direct effects of policy actions, but in evaluating the consequence of these actions we developed <u>predictive scenarios</u> with relatively detailed indications of how the system will change under a set of assumptions, in particular environmental conditions, human exposures, health effects. In Lazio, the baseline scenario ("business as usual") is the situation in 2008, whereas in the first alternative scenario (Lazio Waste strategy) management of waste is changed because of increase in recycling/composting rate, different waste flows, new management plants and no landfilling without pre-treatment. In the second alternative scenario (Green policy), an additional drastic reduction in the total amount of waste is foreseen together with a very high recycling rate.
Scenario(s)	The assessment assumes that in Lazio the <u>2008 baseline</u> situation remains the same in 2016 with identical amount of waste produced with no waste prevention program in operation. Waste collection is performed with highly polluting diesel trucks (Euro 2) using street bins with very low recycling and composting rates. A total of 7 MBTs are operating and 2 incinerators burn refuse-derived fuel (RDF) produced in MBTs; a total of 9 landfills are operating where waste disposal occurs mostly without pre-treatment.

Figure 2. Waste management plants, Lazio 2008



The alternative scenario is taken from the regional waste plan proposed by the Regional Government in 2010 (Waste Strategy) which considers the period up to 2016 and foresees an increase in recycling and composting rate up to 60% using door to door collection of waste. The strategy is intended to recover the material (especially paper and glass), and to use various MBT processes to turn mixed wastes into a Refuse Derived Fuel (RDF) for energy recovery through incineration/gasification. In 2016, only stabilized organic fraction after composting will reach landfills and iron and metals will be separated. The increasing recovery of materials will reduce the use of landfills and they will not accept waste without pre-treatment. According to the plan, 6 new plants for processing waste (2 gasification plants and 6 new MBTs) will be built by 2016, while the number of landfills will remain unchanged. As for the waste collection system, a "door to door" selective waste collection will be implemented to reduce the unsorted waste production, and to increase the selective waste collection. Regarding waste transportation, special attention will be given to the renewal of the trucks collecting bins that will be smaller and less polluting vehicles. For example, in the historic centre of the city of Rome waste collection will be performed by electric vehicles, while in the remaining parts of the city both natural gas vehicles and low emission diesel vehicles will be used. For a portion of the city of Rome, waste transportation will be performed by trains from an intermediate station to the final destination. Waste collection and treatment can have an effect on occupational health and on injuries rates among workers. In theory, when planning collection systems, special care should will be taken to avoid heavy lifting and strain from handling containers, as well as the prevention of injuries at incineration, composting or recycling plants.

The most sustainable scenario is the Green police where a radical application of the EU waste hierarchy principles of reduction of waste (-15% over baseline), high recycling/composting rates (70%) and progressive closure of landfills are applied.

Waste prevention will be a key factor: if the amount of waste generated in the first place is reduced and sorted in the appropriate way for recycling, then disposing of it will automatically become simpler. As a consequence, in the green scenario there will be a reduction in the number of the operating plants: incinerators, landfills and MBTS in Lazio will be 2, 6, and 7, respectively. The criteria for which some plants will be closed are based on the amount of people resident nearby, emission levels, and year of the plant activation. In addition, in the large central area of the city within the railway ring, waste collection and transportation will be performed with electric vehicles.

Table 1: Key aspects of the Lazio Waste Scenarios

Baseline 2008	Waste Strategy 2016	Green Policy 2016
waste prevention: no	waste prevention: reccomended	waste prevention: reccomended and enforced (-15% over baseline)
recycling and composting: 17.8%	recycling and composting: 59.5%	recycling and composting: 70%
waste collection system : mostly by bins and trucks	waste collection system :both by bins and trucks and "door to door"	waste collection system :mostly "door to door"
recycling: street collection of glass and paper	recycling: door to door collection of glass and paper	recycling: door to door collection of glass and paper, centralised collection at recycling centres
vehicle fleet: diesel trucks; trains	vehicle fleet: electric and low emissions vehicles; trains. Electric vehicles in the cetral area (District 1).	vehicle fleet: electric and low emissions vehicles; trains. Electric vehicles in the large cetral area (Railway ring).
Mechanical Biological Treatment: 30.5	Mechanical Biological Treatment: 100%	Mechanical Biological Treatment: 100%
landfill without pretreatment: 69.4%	landfill without pretreatment: 0%	landfill without pretreatment: 0%
waste management facilities: 2 incinerators, 9 landfills, and 7 MBTs	waste management facilities: 4 incinerators, 9 landfills, and 13 MBTs	waste management facilities: 2 incinerators, 6 landfills, and 7 MBTs
occupational health program	improved occupational health program	improved occupational health program

Table 2: Plants for the treatment af MSW according to three policy scenarios: Baseline 2008, Waste Strategy 2016, Green Policy 2016

	Baseline 2008		Waste Strategy 2016		Green Policy 2016	
	n°		n°		n°	
Incinerators	**2**		**4**		**2**	
	Colleferro (RM)		Colleferro (RM)		San Vittore del Lazio (FR)	1 line
	San Vittore del Lazio (FR)		San Vittore del Lazio (FR)	2 lines	Malagrotta (RM)	2 lines
			Malagrotta (RM)	2 lines		
			Albano Laziale (RM)			
Landfills	**9**		**9**		**6**	
	Latina (LT)		Latina (LT)		Latina (LT)	
	Albano Laziale (RM)		Albano Laziale (RM)		Roccasecca (FR)	
	Roccasecca (FR)		Roccasecca (FR)		Colleferro (RM)	
	Colleferro (RM)		Colleferro (RM)		Malagrotta (RM)	
	Bracciano (RM)		Bracciano (RM)		Bracciano (RM)	
	Civitavecchia (RM)		Civitavecchia (RM)		Viterbo (VT)	
	Guidonia Montecelio (RM)		Guidonia Montecelio (RM)			
	Viterbo (VT)		Viterbo (VT)			
	Malagrotta (RM)		Malagrotta (RM)			
MBT + CDR	**7**		**13**		**7**	
	Aprilia (LT)		Aprilia (LT)		Aprilia (LT)	
	Paliano (FR)		Paliano (FR)		Paliano (FR)	
	Viterbo (VT)		Viterbo (VT)		Viterbo (VT)	
	Albano Laziale (RM)		Albano Laziale (RM)		Roma (RM)	malagrotta 1 and 2
	Roma (RM)	salario	Colfelice (FR)		Colfelice (FR)	
	Colfelice (FR)		Roma (RM)	malagrotta 1 and 2	Roma (RM)	salario
	Roma (RM)	rocca cencia	Roma (RM)	salario	Roma (RM)	rocca cencia
			Roma (RM)	rocca cencia		
			Latina (LT)			
			Rieti (RI)			
			Colleferro (RM)			
			Bracciano (RM)			
			Guidonia Montecelio (RM)			

Figure 3. Waste Flows – Baseline (2008)

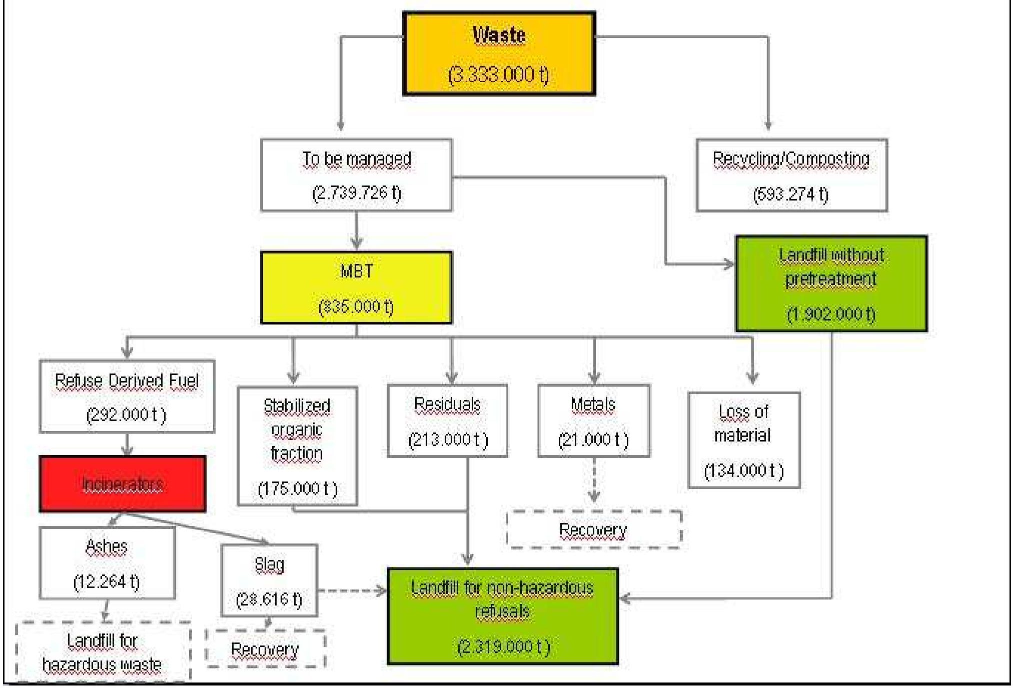
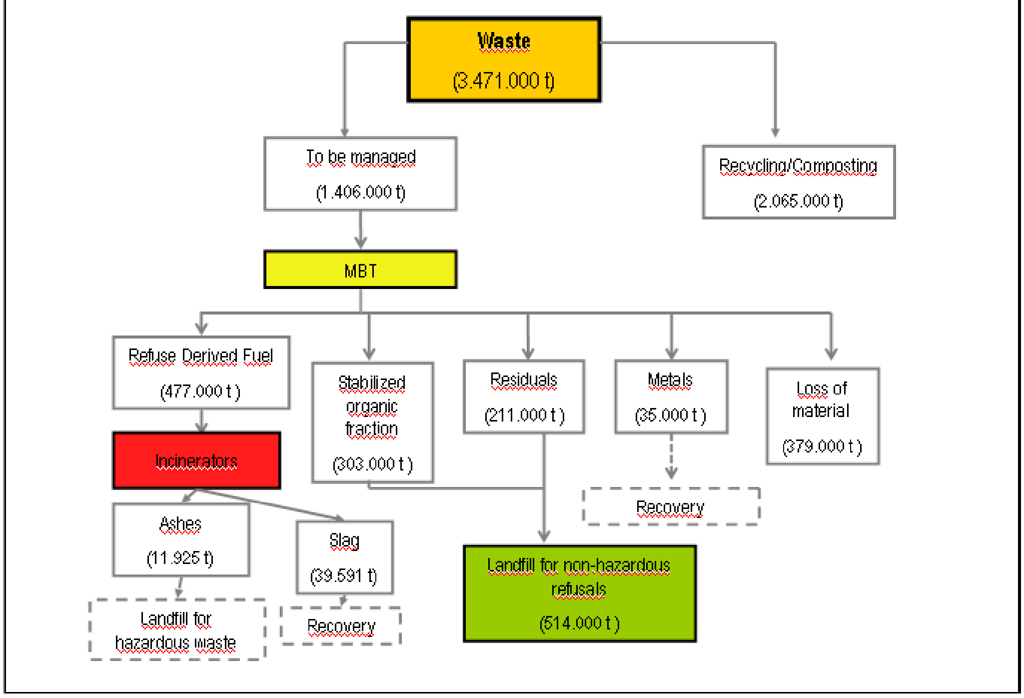


Figure 4. Waste Flows – Waste Strategy (2016)



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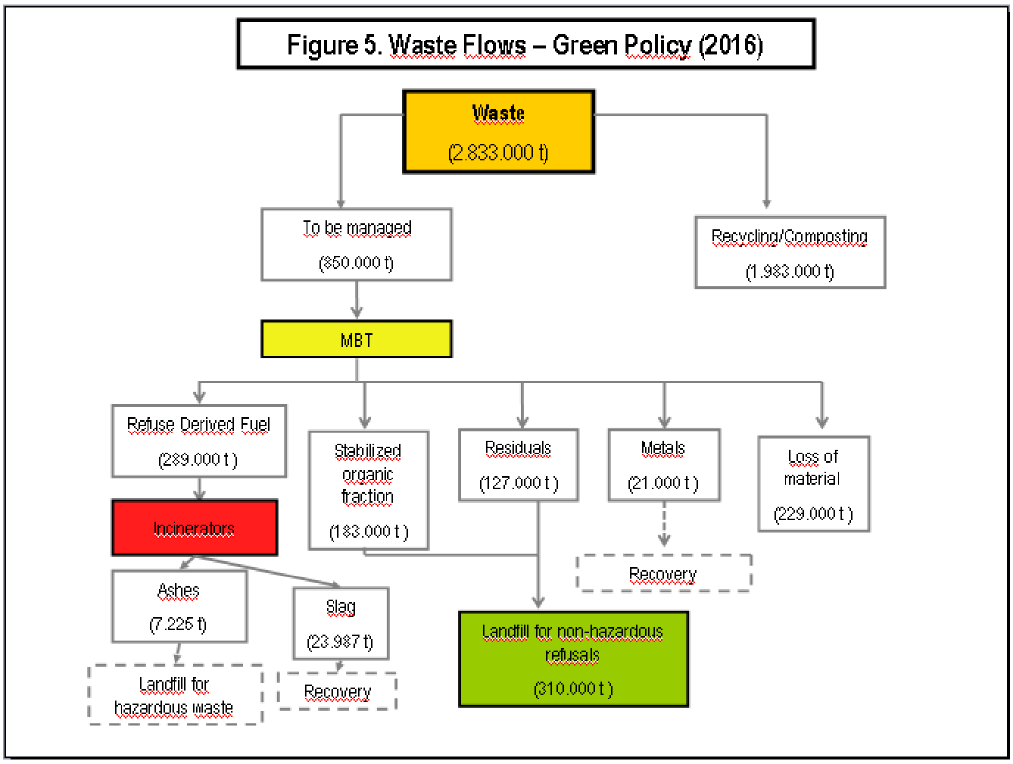

Figure 5. Waste Flows – Green Policy (2016)
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<tr><td>Study area(s)</td><td>
The study was carried out for the Region of Lazio (Central Italy, it includes the city of Rome) with 5,561,017 inhabitants (as at January 1st 2008). Lazio is characterized by a strong heterogeneity in the distribution of population: more than 75% of residents are concentrated in the province of Rome, particularly in the city of Rome where about 2.7 million people live (49% of regional population). However, most of the municipalities (54% of total) have less than 3.000 inhabitants, with only 13.2% of municipalities having more than 15.000 residents. The Lazio average density is 323 inhabitants/km^2, higher than the national density (199inhabitants/km^2) Population data at the smallest unit of aggregation for census 2001 were available in Lazio by census block (CB) (total of 27,875 CB (mean 183, SD 234 inhabitants per unit)).
The Lazio road system is a radial system with Rome as the central point. A system of crossroads provides interconnection between different parts of the region. The radial structure is also recognizable in the rail network.
See Figure 2: Map of Lazio, the road system and the waste management plant in 2008.
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<tr><td>Dates/time periods</td><td>
Since the scenarios will be fully operating in 2016, we decided to perform the assessment considering the 35-year period 2016-2050 for the calculation of the health impact. In particular, for the calculation of the effect of transportation on survival (and Years of Life Lost – YLL- and Disability Adjusted Life Years- DALY), we assumed that the exposure to trucks emissions will be operating for the period 2016-2030 (and health effects were calculated up to 2050). Similarly, we assumed that incinerators/gasification plants operating in 2016 will be operating until 2030 and the health effects were estimated up to 2050. For landfills operating in 2016, we assumed that the emissions will last up to 2045 (30 years) and the effects on
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	newborns were calculated up to then (an assumption in agreement with the available knowledge that landfilled biodegradable waste starts to emit biogas a few years after deposit and continues to do so for several decades).
Study population(s)	We performed the assessment for different sectors of the Lazio population. For the effects of emissions of transport, we considered the entire population of the Rome urban area (about 2.5 million inhabitants at the 2001 Census). According to the same 2001 Census data there were 12,041 workers employed in the waste industry in Lazio, and we considered for the baseline evaluation that 80% were blue collar workers (9,633) potentially at risk of occupational injuries. The dimension of this occupational group has been changed for the two alternative scenarios proportionally to the amount of waste produced. For the general population, we considered for the assessment residents living 3 km from incinerators, 2 km from landfills and 200 meters from MBTs. People were identified as living within the census blocks on the basis of the GIS data. Specific sex and age (5 year bands) groups were considered for specific health outcomes and the population was further divided in a five-level area-based index of socioeconomic status (SES). The index was developed by census block using the 2001 census data of Lazio, similar to the method previously developed for the city of Rome (Cesaroni et al, 2006). We considered census information that represented various socioeconomic parameters: occupation, education, housing tenure, family composition, and foreign status. We performed a factor analysis to create a composite indicator, and we used the quintiles of its distribution in census blocks to obtain a 5-level area-based index.
Exposures/risk factors	The following pollutants/factors were included within the scope of this assessment: • Particulates and gases (PM_{10}, NO_2) → from transport, incinerators, landfills engines • Dioxins and other combustion products→ from incinerators • Bioaerosols (endotoxins) → from MBTs and landfills • Biogas → from landfills • Odours → from MBTs and landfills • Occupational injuries→ from waste collection and transport
Health outcomes	The following health outcomes were considered: • Mortality (mainly respiratory and cardiovascular) → from PM_{10},and NO_2→ from transport, incinerators, and landfills engines • Adult cancers → from emissions of incinerators • Congenital malformations and low birth weight → from landfills • Respiratory symptoms → from MBTs and landfills • Occupational injuries→ from waste collection and transport • Odour annoyance → from MBTs and landfills All these outcomes were combined to calculate Disability Adjusted Life Years (DALYs).
Stakeholders	The list of stakeholders in waste management includes industry, central / regional governments, city councils, NGOs, service users, private sector, citizens, scientists and media. It should be noted that several stakeholders are present in the waste management area especially before waste formation: industry, packing, delivery of goods, and citizens are all involved in the waste formation as well as in the "waste minimization" process. On the other hand, there are several stakeholders at the end of the process where "waste" represents important economical resources of material (glass, paper, etc) and energy. Since environmental control is also crucial at the end

	of the process, public institutions play an important role. We have appreciated that there are several conflicting interests among the various stakeholders, especially in Italy, e.g. national policy versus local policy, industrial interests versus environmental interests, environmental sustainability and employment, waste minimization and energy production. These conflicting interests, together with citizens' concerns of health effects, make choices of waste management a very controversial area. The full list of stakeholders includes: • European, national and regional policymakers and authorities (Ministries of Environment, Ministries of Health) • Institutions for environmental control and public health • Transportation industry • Waste management companies and industry • Consumers, NGOs and lobby groups (e.g. for composting and recycling) • Citizens associations • Media • Researchers
Stakeholder participation	In Lazio, discussions were held with the Regional Authority responsible for the regional Waste Strategy, especially regarding the sites of the new plants and the waste flows. Meetings were held with the main waste company for the Rome municipality mainly responsible for waste collection and transportation. Environmental data and dispersion models were discussed with the Regional Environmental Protection Agency. There were several discussions with city councils and community groups regarding the proposal of new incinerators and with expert journalists in the field. All these discussions were conducted in an informal way.
Exposure assessment	
Source-exposure variables	As indicated in the causal diagram (Annex 1), the following variables were used to estimate exposures: • Emissions; for each management process and for each type of pollutants, emissions per ton of treated waste (Environs, 2004; see Annex 2) • Meteorological data - (wind speed, wind direction, temperature, solar influx (W/m^2)) • Waste management sites - incinerator and landfill characteristics (location, stack height, stack diameter, gas exit velocity, gas exit temperature) • Authorized emission data for the Waste management sites • Population data -population at census area level • Road network – TeleAtlas Multinet road data • Map of concentrations – PM_{10} and NO_2 concentration maps at 100x100m grid (combination of dispersion modelling and the waste transport model).
Exposure metrics	• Mean annual PM_{10} and NO_2 population-weighted exposure • Distance from incinerators, landfills and MBTs • Employment in the waste industry
Sources and emissions	On the basis of amount of waste per management process (data from the Regional Waste Authority) and specific air emission factors (see Annex 2), estimates of the

	total amount of pollutants emitted on a yearly basis were made.
Concentrations/hazard intensity	Concentrations were modelled in two ways: 1. Concentrations arising from waste transport were modelled using a purpose build GIS model (see annex 3). The waste transport model uses information on waste generation capacity, road network and types of road, storage bins and collection vehicles to estimate traffic flow attributable to waste collection and waste transport. A shortest cost path analysis constructs routes from collection points to waste management sites giving high costs to minor roads and low costs to major roads. Total amount of waste collection vehicles is then calculated and gridded to a 100x100m raster. A kernel file, which is modelled in ADMS-Urban, reflects dispersion of traffic emissions around a 100x100 grid cell. The kernel is then used in the ArcInfo Focalsum function to create a modelled concentration grid. This approach derives from a methods developed at Imperial College (Vienneau 2009). 2. Concentrations arising from incinerators and/or landfills were modelled using the atmospheric dispersion model – ADMS-Urban. Meteorological data for 2008 and 2009 from the nearest available met station was used NO_2 and PM_{10} concentrations were modelled by ADMS-Urban till approximately 10 km away from the incinerators and landfills.
Exposures	Area weighted concentrations were calculated in ArcGIS by intersecting the concentrations grids with the census boundaries. This then provided the link between population and concentrations. Population-weighted exposure levels were calculated for the specific population of interest.
Health effects and impacts	
Exposure-health effect variables	Background sex-age specific cancer incidence data were retrieved from the pool of the Italian cancer registries (www.registri-tumori.it). Mortality statistics were available from the Italian Institute of statistics (http://demo.istat.it/). Prevalence of congenital malformations at birth was derived from the Annual Report (data for 2000) of the International Clearinghouse for birth defects monitoring system (www.icbd.org) for Italy. Background prevalence data for respiratory symptoms in the adult population and odour annoyance were derived from the study by Herr et al, 2003.
Health metrics	The health metric for each of the following outcomes is the annual cumulative (2016-2050) number of cases / diseases attributable to waste management (Attributable burden): • Annual and cumulative incidence of cancer in adults • Annual prevalence of congenital malformations in children and cumulative incidence of cases • Annual prevalence of low birth weight and cumulative incidence of cases • Annual mortality • Annual prevalence of respiratory disorders • Annual prevalence of odours annoyance

Exposure-response functions	The PM_{10} and NO_2 Exposure Response Functions (ERF) derive from studies on traffic-related air pollution. They were taken from the systematic review conducted by the INTARESE work package on transport (WP3.1/WP1.3). For a 10μg/m^3 increase in outdoor PM_{10} concentrations, RR for all natural mortality is 1.060 (95%CI 1.030-1.090). For 10 μg/m^3 NO_2, RR= 1.06 (95%CI=1.04-1.08) (Refer to Toolbox database derived from document: Concentrations - response functions for traffic-related air pollution, IRAS). For morbidity, we used our systematic review of the literature on waste (Porta et al, 2009) providing relative risks for the following outcomes: -Cancer cases near incinerators (within 3 km): RR=1.035 (95% CI=1.03-1.04) (Elliott et al, 1996). Such effect was scaled in the cancer model according to plant and population characteristics (see Annex 4); - Respiratory symptoms (cough on rising and during the day) near MBTs (200 meters) or landfills (200 meters): OR=3.18 (95% CI 1.24 to 8.36) which is equivalent to a Prevalence Rate Ratio= 2.25 (Herr et al, 2003); -Low birth weight near landfills (2km): RR=1.06 (99% CI=1.052-1.062) (Elliott et al, 2001). This coefficient has been halved on the assumption that the methods to capture biogases from landfills has been improved over the years; -Congenital anomalies near landfills (2km): RR=1.02 (99% CI=1.01-1.03) (Elliott et al, 2001). This coefficient has been halved on the assumption that the methods to capture biogases from landfills has been improved over the years; - Severe odour annoyance near MBTs (200 meters) or landfills (200 meters): 5.4% (Herr et al, 2003); Finally, for occupational injuries we derived the accident rates (per 100,000 workers in the waste industry) from a comprehensive official UK report (HSE, 2009) - Fatality rate: 8.5 - Major injury accident rate: 423 - Over 3d injury accident rate: 2093 - Total accident rate: 2525
Impact metrics	We estimated for each scenario and for each process: Attributable cases (n) Years of Life Lost (YLLs) Disability Adjusted Life Years (DALYs)
Impact assessment methods	First, exposure classes were defined and the attributable cases calculated: $AC = Rate_{unex} * ER * Pop_{exp}$ where AC = the attributable cases $Rate_{unex}$ = background prevalence/incidence rate in the general population ER = excess risk in the exposed population (relative risk – 1)

	Pop_{exp} = number of exposed subjects Years of Life Lost (YLL) attributable to PM_{10} and NO_2 exposure from transport and plants emissions were estimated. On the assumption to follow up until 2050 the entire 2016 population living close to emission sources, and that their mortality rate was similar to that of the national population, we estimated YLLs attributable to PM_{10} and NO_2 exposure as derived from the air dispersion model. In particular, we assumed that the impact of PM_{10} and NO_2 will be noticeable only during 2016-2035. We have used the system of spreadsheets provided by the IOM institute (http://www.iom-world.org/pubs/IOM_TM0601.pdf?PHPSESSID=551b9ccae82ad1127a41db2c144d6d9a). DALYs were calculated for the three scenarios. AC was converted to DALYs by including severity weights (S) and health state durations (D): DALY = AC * D * S. For the calculation of DALYs, severity weights (or disability weights, S) give an indication of the reduction in capacity due to the specific disease. A weight factor, varying from 0 (healthy) to 1 (death), is determined by experts (clinicians, researchers, etc). In our case, severity weights were mostly adapted from the Victorian Burden of Disease Study (2005). In particular, the following severity weights/and duration of disease (D, years) were adopted. -Mortality = 1 -Cancer = 0.44/12.6 years -Respiratory symptoms = 0.08/1 year (prevalence) -Low birth weight = 0.106/ 79.6 years -Congenital anomalies = 0.17 / 79.6 years -Severe odour annoyance = 0.03/ 1 year (prevalence) - Occupational injuries - Fatality = 1 - Major injury = 0.208 / 37.3 years - Over 3d injury = 0.10 / 3.3 years
Uncertainty analysis	
Main sources of uncertainty	We have listed the sources of uncertainties for each step of our evaluation. Significant sources of uncertainty were assessed according to the IPCC (2005) classification. The level of confidence was systematically recorded for each step in the assessment indicating correctness of each model, analysis or statement using value out of 10 where: 9 is very high confidence; 8 is high confidence; 5 is moderate confidence; 2 is low confidence; and <2 very low confidence. 1. Scenarios The reduction of waste and the improvements in recycling and composting across Lazio, detailed in the two scenarios, will lead, in the long term, to environmental, social and economic benefits. However, a potential negative impact with both of the scenarios relates to the increase in road transport of waste as different services are introduced to collect more recyclables. The increase in road transport could have negative implications for local air pollution levels although vehicle emissions abatement technology should minimize this potential risk. Therefore, the main limitation of our scenarios was the uncertainty about the impact of the recycling industry. Overall, we think we have characterized the scenarios with a moderate

	level of confidence. 2. Waste generation and management As expected, there were inadequacies in data availability and reliability on MSW indicators. However, a crosscheck has been done between various sources and we have high confidence in the summary statistics reported and in the waste flows described. 3. Population characteristics and exposure to air pollutants We had relatively high quality geo-referenced data for incinerators, landfills and MBT's. Small problems, however, were faced in estimating the exposed population because the size of some landfills is not known, and the unit of the available population data (census block) did not fit our needs. Fortunately population data by age and sex was available at the local level even though they were based on the last census. Overall, we have very high confidence on the population data close to the plants. The results of the air dispersion models depend on the quality of the input data. We had operational data or authorized values during recent years. However, some plant characteristics were missing and had to be estimated. On the other hand, we could rely on high quality meteorological data for most of the plants and topography was also considered. Overall, we have a high confidence in the estimated air pollution concentrations close to management plants and along roads. 4. Excess-risk and exposure-response functions The application of excess-risk estimates based on distance from the plants has been problematic because of several difficulties in interpreting of epidemiological studies. We have tried to address the issue in a transparent way by conducting a systematic evaluation. However, as underlined on several occasions, we have moderate confidence in the excess risks used for the impact assessment of cancer cases and adverse reproductive outcomes. The effect estimates for respiratory symptoms and odour annoyance are also based on a limited number of studies and our confidence on them is moderate. On the other hand, we have high confidence in the coefficients for long-term effects of PM_{10} and NO_2 on mortality. 5. Quantification of the health impact. The quantification has been straightforward in terms of calculating excess cases as there are no difficulties in finding the appropriate health statistics and taking into account the particular population characteristics near the facilities. However, the most difficult part is translating the effect studied from old plants using old technologies to new facilities. We have clearly stated our assumptions and also have tried to evaluate the consequence of changing some of the parameters. Overall, we have moderate confidence in our method to estimate excess cancer cases and reproductive outcomes. On the other hand, the life table approach is rather robust although it is difficult to verify some of the assumptions (time of the effect, stability of the population, constant mortality). Finally, because a variety of illegal disposal practices exists and because it is difficult to estimate the amount of waste that is disposed of illegally, to determine emissions, exposure levels and health effects is difficult. For all of these reasons, our quantification of the health impacts has a moderate level of confidence.
Results	
Outputs	As indicated in the causal diagram (Annex 1) the following indicator variables are

	used to estimate health effects: • Cases of disease attributable to waste management • DALYs (including YYL) attributable to waste management

Main findings

1. Scenarios, waste generation and management

At the baseline the total volume of waste produced was 3.330 mTonnes, of which 0.593 was recycled/composed, 1.902 was landfilled without pre-treatment, and 0.835 was managed with Mechanical and Biological Treatment (with production of Refuse Derived Fuels (RDFs) for incineration). Under the Waste strategy, the recycling/composting rate will be increased up to 60% and no landfill will be in use without pre-treatment. Under the Green policy, the amount of waste production will decrease of 15% and recycling/composting rate will increases to 70%. (see also Figures 3-5 for the schematic representation of the waste flows)

Table 3. Waste generation, management and plants for the treatment of Municipal Solid Waste in Lazio, Italy, according to three policy scenarios: Baseline 2008, Waste Strategy 2016, Green Policy 2016.

Management	Baseline 2008		Waste Strategy 2016			Green Policy 2016		
	mTonnes	%	mTonnes	%	% change over baseline	mTonnes	%	% change over baseline
Total Volume	3.333		3.471		4.1	2.833	15.0	-15.0
Recycling/Composting	0.593	17.8	2.065	59.5	248.0	1.983	70.0	234.3
To be managed	2.740	100.0	1.406	100.0	-48.7	0.850	100.0	-69.0
Landfill without pretreatment	1.902	69.4	0	0.0	-100.0	0	0.0	-100.0
Mechanical Biological Treatment	0.835	30.5	1.406	100.0	68.3	0.850	100.0	1.8
RDF for incineration	0.292	10.7	0.477	34.0	63.5	0.289	34.0	-1.2
Stabilized organic fraction	0.175	6.4	0.303	21.6	73.3	0.183	21.6	4.8
Iron and other metals	0.021	0.8	0.035	2.5	68.9	0.021	2.5	2.1
Residuals	0.213	7.8	0.211	15.0	-1.0	0.127	15.0	-40.1
Loss of material	0.134	4.9	0.379	26.9	182.7	0.229	26.9	70.7
Number of plants								
Incinerators	2		4			2		
Landfills	9		9			6		
MBTs	7		13			7		

2. Emissions. Table 4 illustrates the amount of emissions (in tonnes per year) of various pollutants according to the three scenarios. A considerable decrease (up to 90%) will be seen for most of the pollutants (for instance particulate matter(PM) emissions will go from 17.9 to 6.6 and 4.13 tonnes/year, respectively) with the exception of some metal (e.g. arsenic and mercury) because of the increase in incineration of RDFs (waste and green strategies).

Table 4. Emissions (Tons per year) of several polluting soubstances into air according to three policy scenarios: Baseline 2008, Waste Strategy 2016, Green Policy 2016.

Compound	Baseline 2008		Waste Strategy 2016		% Change over baseline	Green Policy 2016		% Change over baseline
	Total (Tons)	per inhabitant (grams)	Total (Tons)	per inhabitant (grams)		Total (Tons)	per inhabitant (grams)	
PM	17.86	3.213	6.62	1.190	-63.0	4.13	0.742	-76.9
Cadmium	0.02	0.003	0.00	0.001	-71.8	0.00	0.001	-82.9
Nickel	0.12	0.021	0.09	0.016	-22.4	0.05	0.010	-53.1
Arsenic	0.01	0.002	0.02	0.004	84.5	0.01	0.002	11.6
Mercury	0.01	0.002	0.02	0.004	150.8	0.01	0.002	51.7
NOx	2,047.21	368.203	847.53	152.433	-58.6	518.97	93.339	-74.7
SO2	141.62	25.471	67.87	12.208	-52.1	41.06	7.386	-71.0
HCl	28.97	5.211	27.65	4.973	-4.6	16.72	3.007	-42.3
HF	6.97	1.254	1.52	0.273	-78.3	0.92	0.165	-86.9
VOCs	67.21	12.087	68.53	12.326	2.0	42.51	7.645	-36.7
Cl-VOCs	5.86	1.054	0.58	0.105	-90.0	0.35	0.064	-94.0
Benzene	0.01	0.001	0.00	0.001	-57.1	0.00	0.000	-66.5
Dioxins/Furans	1.03E-06	1.85E-07	6.71E-07	1.21E-07	-34.9	4.06E-07	7.30E-08	-60.7

Figure 6-10 illustrates for each pollutant the relative distribution of the sources by scenario.

Figure 6. Relative contribution of the different sources to waste related PM - emissions

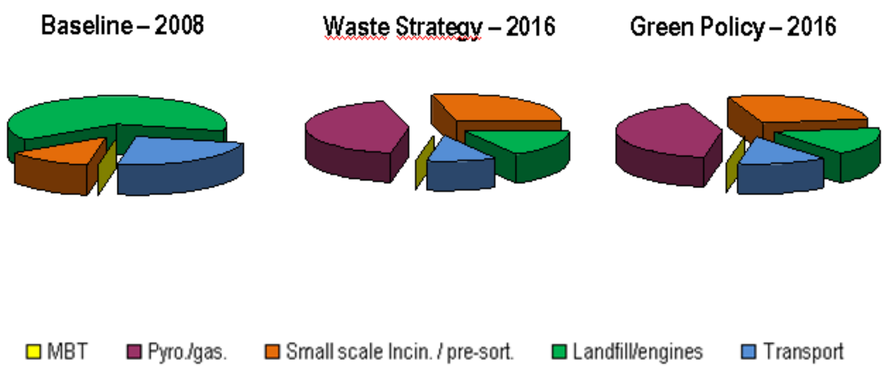


Figure 7. Relative contribution of the different sources to waste related Nickel - emissions

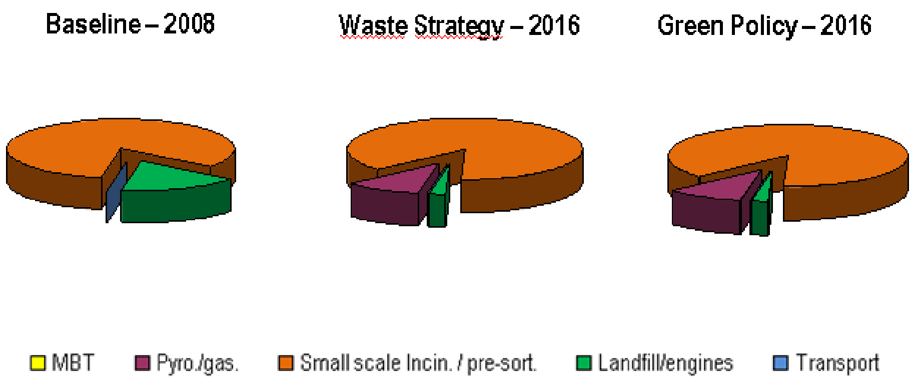


Figure 8. Relative contribution of the different sources to waste related NOx - emissions

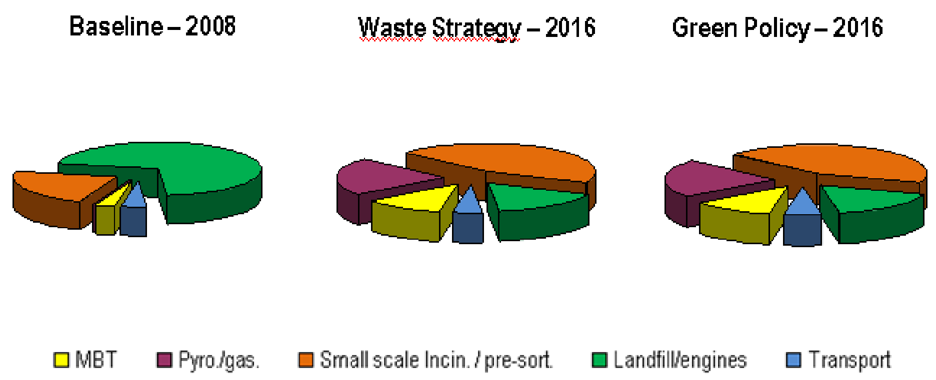


Figure 9. Relative contribution of the different sources to waste related VOCs - emissions

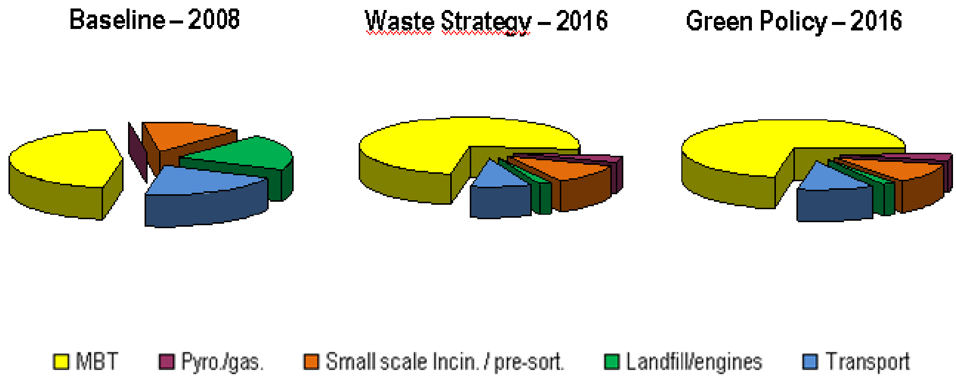
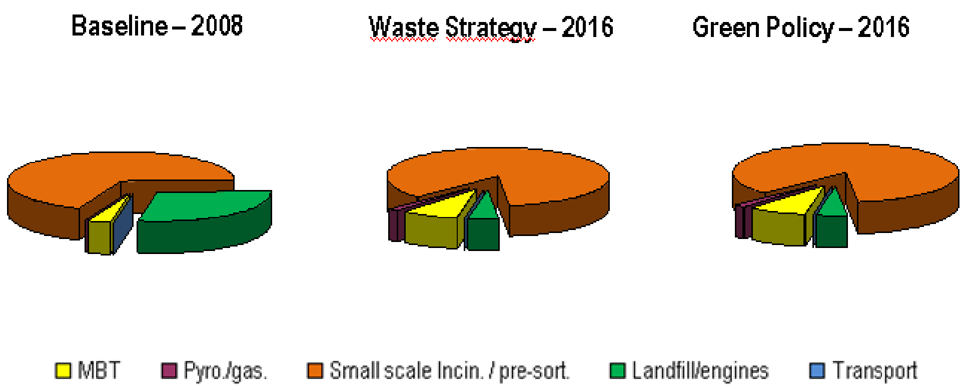


Figure 10. Relative contribution of the different sources to waste related Dioxins/Furans - emissions



3. Population involved and characteristics. A total of 36,191 people live nearby MSW facilities at baseline (23,917 close to the two incinerators, 2345 close to MBTs, and 9929 close to landfills). Through the implementation of the waste strategy, the number of people living close to plants will increase to 51.639 subjects, especially because of two new incinerators (from 23,917 to 39,284 subjects). On the other hand, the Green policy will decrease to 14,606 the population involved with an important change of people residents close to incinerators and landfills. Important differences by socioeconomic status were present at baseline, with people of lower socioeconomic status being relatively more exposed than more affluent people to waste management. In general, the waste policies will not affect the relative inequity in this context, although the absolute number of exposed people decreases in the Green policy. In addition to the general population, waste workers were estimated: about 10,000 for the baseline and the waste strategy whereas the number will decrease to about 8,300 under the Green Strategy.

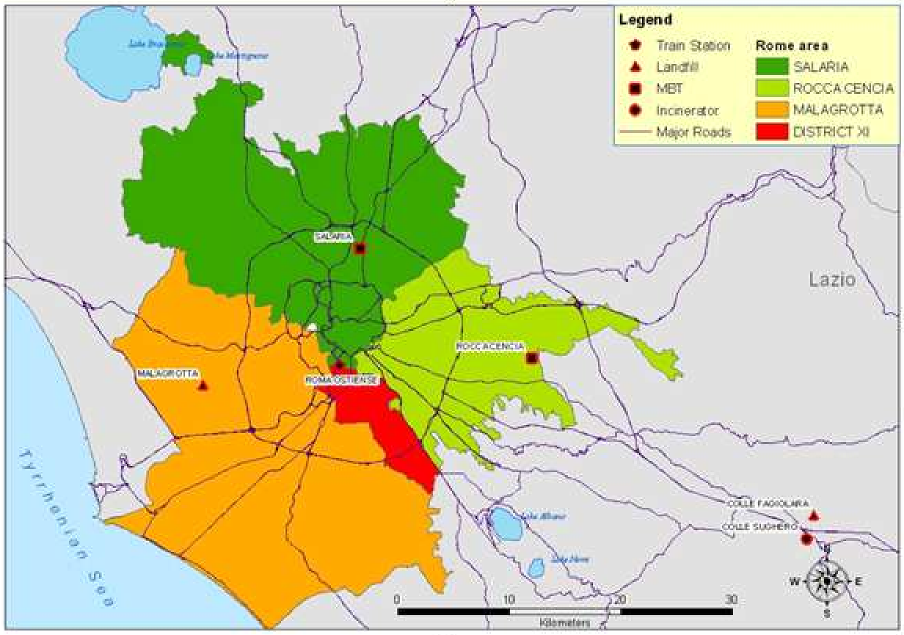
Table 5. Characteristics of residents living in proximity of incinerators, landfills and MBTs in Lazio according to policy scenarios

	Baseline 2008		Waste Strategy 2016			Green Policy 2016		
	n°	%	n°	%	% change over baseline	n°	%	% change over baseline
Incinerators (n. plants)	**2**		**4**			**2**		
Total residents (0-3 km)	23917	100	39284	100	64.3	8809	100	-63.2
males	11625	48.6	19247	49.0	65.6	4420	50.2	-62.0
females	12292	51.4	20037	51.0	63.0	4389	49.8	-64.3
Socioeconomic position								
high	2449	10.7	2515	6.8	2.7	278	3.5	-88.6
medium high	7852	34.4	9470	25.5	20.6	870	11.1	-88.9
medium	8902	39.0	11269	30.4	26.6	1256	16.0	-85.9
medium low	2549	11.2	7673	20.7	201.0	1957	24.9	-23.2
low	1087	4.8	6190	16.7	469.4	3493	44.5	221.3
Age (years)								
0	260	1.1	495	1.3	90.7	131	1.5	-49.6
1 - 14	3116	13.0	5486	14.0	76.0	1339	15.2	-57.0
15 - 44	10282	43.0	17544	44.7	70.6	4098	46.5	-60.1
45 - 64	6202	25.9	9824	25.0	58.4	2113	24.0	-65.9
65+	4057	17.0	5935	15.1	46.3	1128	12.8	-72.2
Landfills (n. plants)	**9**		**9**			**6**		
Total residents (0-2 km)	9929		9929		0.0	3444		-65.3
males	4916	49.5	4916	49.5	0.0	1695	49	-65.5
females	5013	50.5	5013	50.5	0.0	1749	51	-65.1
Socioeconomic position								
high	84	0.9	84	0.9	0.0	84	2.6	0.0
medium high	650	7.1	650	7.1	0.0	535	16.7	-17.6
medium	1852	20.2	1852	20.2	0.0	141	4.4	-92.4
medium low	2944	32.1	2944	32.1	0.0	1590	49.7	-46.0
low	3631	39.6	3631	39.6	0.0	847	26.5	-76.7
Age (years)								
0	153	1.5	153	1.5	0.0	52	1.5	-66.2
1 - 14	1539	15.5	1539	15.5	0.0	498	14.5	-67.6
15 - 44	4586	46.2	4586	46.2	0.0	1518	44.1	-66.9
45 - 64	2356	23.7	2356	23.7	0.0	846	24.6	-64.1
65+	1295	13.0	1295	13.0	0.0	530	15.4	-59.1
MBT (n.plants)	**7**		**13**			**7**		
Total residents (0-200 m)	2345		2426		3.5	2353		0.3
males	1158	49.39	1198	49.4	3.5	1162	49.4	0.3
females	1187	50.61	1227	50.596	3.4	1191	50.6	0.3
Socioeconomic position								
high	484	21.0	487	20.5	0.5	484	20.9	0.0
medium high	92	4.0	94	3.9	2.1	92	4.0	0.0
medium	29	1.3	39	1.6	34.0	5	0.2	-82.5
medium low	902	39.1	904	38.0	0.2	903	38.9	0.1
low	799	34.7	855	35.9	6.9	835	36.0	4.5
Age (years)								
0	29	1.2	30	1.3	4.8	29	1.2	0.7
1 - 14	334	14.26	349	14.4	4.3	337	14.3	0.7
15 - 44	1081	46.12	1118	46.1	3.3	1083	46.0	0.2
45 - 64	645	27.5	664	27.4	3.0	646	27.5	0.2
65+	255	10.89	266	10.9	4.0	257	10.9	0.7

4. Waste transport in Rome. Figure 11 illustrates the waste management facilities in Rome and the catchment areas. At baseline, a total of 18,916 journeys of trucks per year (average distance 19.7 km) were necessary for the first transfer of waste from the census blocks to the management facilities. In addition, a total of 5 journeys (average distance 33.39 km) were necessary for the second transfer from MBTs to other destinations. Under the baseline scenario, a total of 9,899,592 km's per year were travelled. In the Waste strategy, the number of journeys and the kilometers travelled were reduced of 37.2% and 38.2%, respectively. The reduction was even more radical in the Green policy scenario, with a reduction of 65.3% in journeys and 64.5% in kilometers travelled.

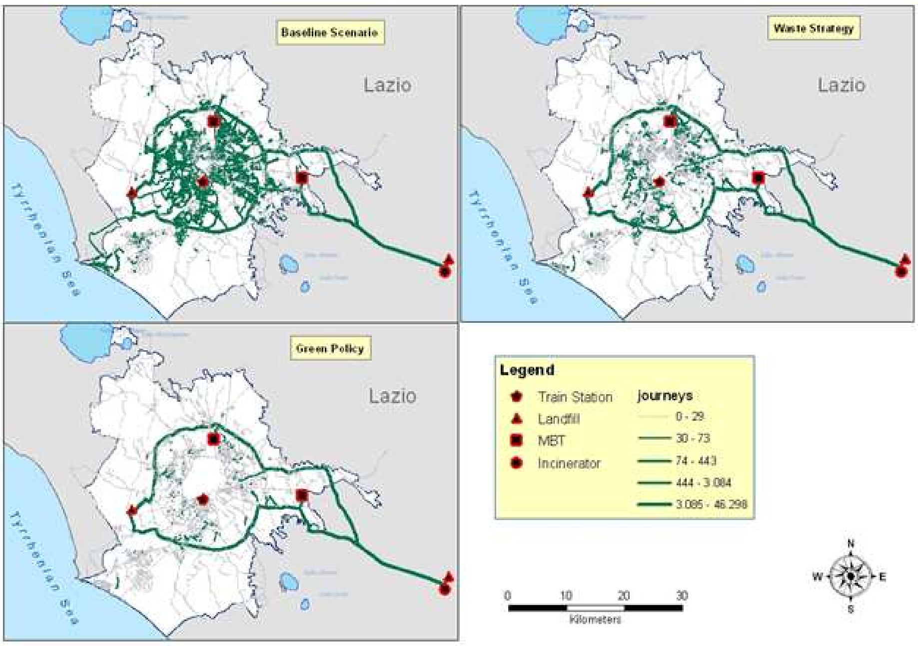
The average distance between the CB and the facilities in the two alternative scenarios was also decreased over the Baseline scenario: about 14,5 km versus 19,7 km. An overall transport impact is shown in figure 12.

Figure 11. Location of Management Solid Waste facilities in Rome[1]



[1]Catchment areas

Figure 12. Annual trucks journeys for waste transport in Rome by scenario



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5. <u>Pollutants concentrations and population weighted exposure.</u> The contribution of waste transport to the average annual concentration of NO_2 in Rome is 0.01988 μg/m^3 at baseline, 0.00198 μg/m^3 with waste strategy and 0.00118 μg/m^3 with at green policy (see Table 6 and Figures 13-18 for details).

Table 6. NO2 concentration and population weighed exposure from transport according to three policy scenarios in Rome: Baseline 2008, Waste Strategy 2016, Green Policy 2016

Management	Baseline 2008		Lazio Waste Strategy 2016			Green Policy 2016		
					% change over baseline			% change over baseline
Average annual concentration	0.01988		0.00198		-90.1	0.00118		-94.0
(S D)	0.133		0.009			0.005		
Minimum:	0		0			0		
Maximum:	7.06480		0.26540			0.16020		
Population weighted exposure	0.02030		0.00186		-90.9	0.00103		-94.9
Population by NO2 concentration quintiles								
					% change over baseline			% change over baseline
Total population	2546804	%	2546804	%		2546804	%	
Population by NO2 quintiles								
0	2762	0.1	26970	1.1	876.3	148890	5.8	5289.8
0 - 0.0277	2282054	89.6	2498764	98.1	9.5	2385831	93.7	4.5
0.0278 - 0.0554	117807	4.6	13777	0.5	-88.3	10076	0.4	-91.4
0.0555 - 0.1110	75283	3.0	6067	0.2	-91.9	1674	0.1	-97.8
0.1111 - 0.2770	40366	1.6	1226	0.0	-97.0	334	0.0	-99.2
0.2774 - 7.0648	28532	1.1	0	0.0	-100.0	0	0.0	-100.0

Figure 13. NO2 concentrations ($\mu g/m^3$) from waste transport – BASELINE 2008

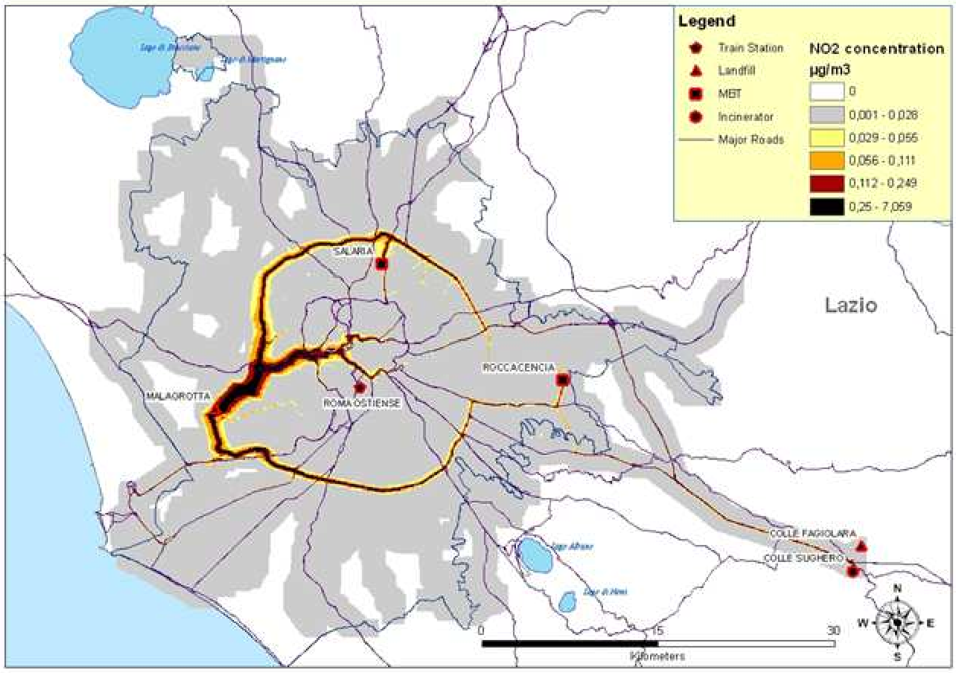


Figure 14. NO2 concentrations (µg/m3) from waste transport – BASELINE 2008

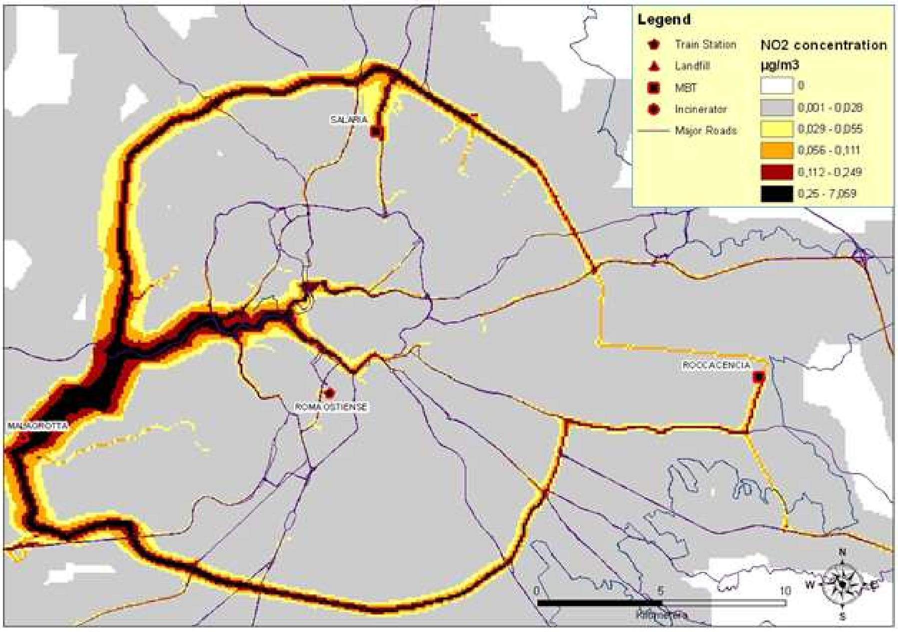


Figure 15. NO2 concentrations (µg/m3) from waste transport – WASTE STRATEGY 2016

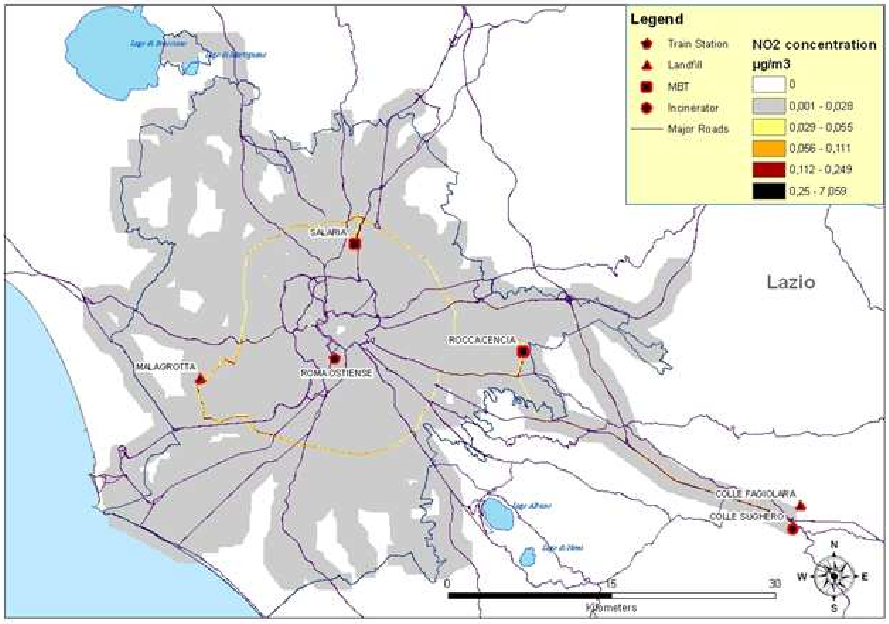


Figure 16. NO2 concentrations (µg/m3) from waste transport – WASTE STRATEGY 2016

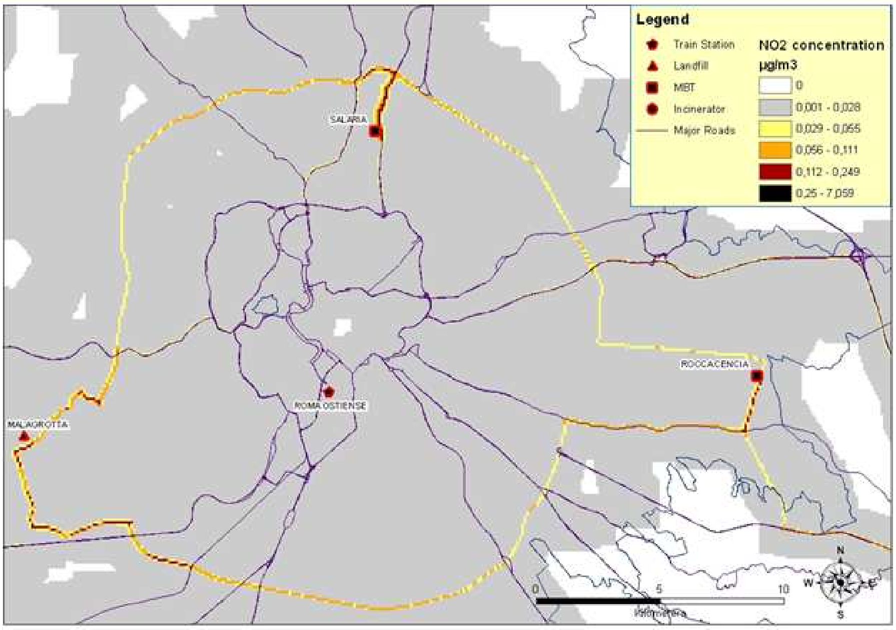


Figure 17. NO2 concentrations (µg/m3) from waste transport – GREEN POLICY 2016

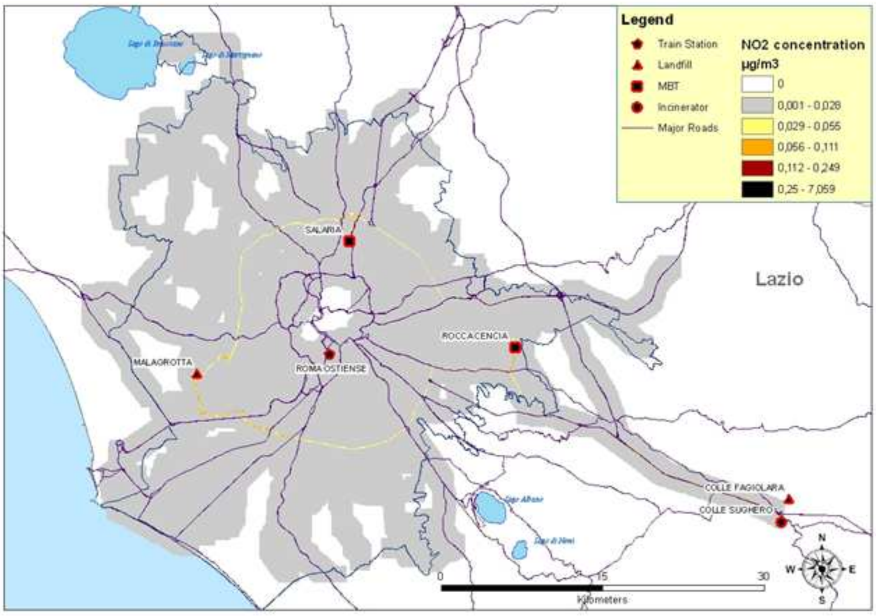
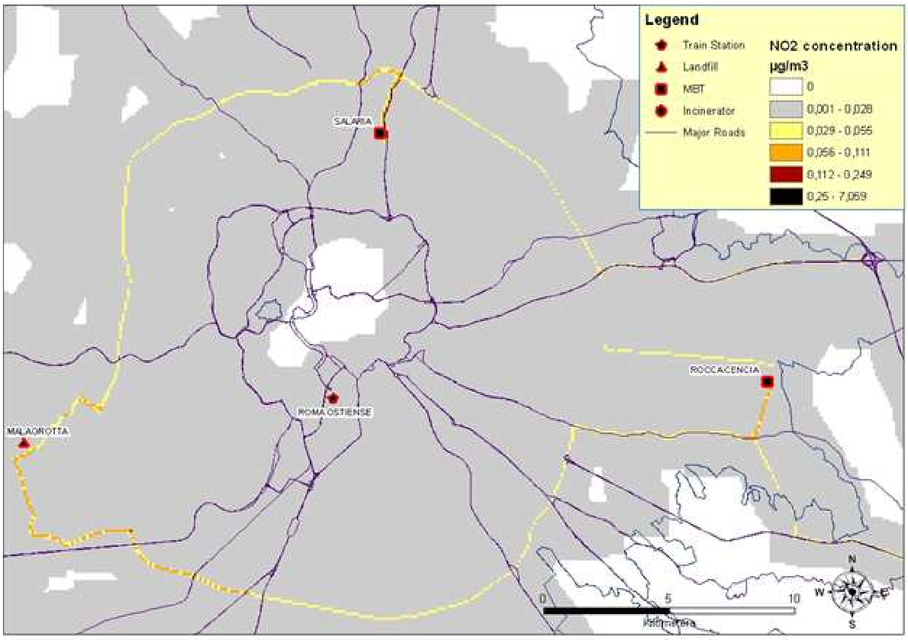


Figure 18. NO2 concentrations (µg/m3 from waste transport – GREEN POLICY 2016



As a consequence, the implementation of the waste and green strategy results in an important reduction of the population weighted exposure (-90%, -95 %, respectively). A total of 28,532 people living in Rome are exposed to the highest NO_2 concentrations (0.277-7.065) at the baseline but, due to changes in transport policies, this number decreases to 0 with the waste and green strategy, respectively.

Annual average concentration near all landfills and incineration plants were estimated with the ADMS model. The contribution from the plants was rather small with the highest values found for the large landfill of Malagrotta in Rome. The population weighted NO_2 (and PM) exposure levels were also relatively low, ranging from 0.05 to 0.7 µg/m^3 for landfills and 0.03 to 0.06 for incinerators µg/m^3.

Table 7. Concentration and population weighted exposure from plants emissions in Lazio at 2008.

	BRACCIANO		CIVITAVECCHIA		GUIDONIA		ALBANO		ROMA	
	Landfill - Cupinoro		Landfill - Fosso Crepacuore		Landfill - Inviolata		Landfill - Cecchina		Landfill - Malagrotta	
	NO2 2008	PM10 2008	NO2 2008	PM10 2008	NO2 2008	PM10 2008	NO2 2008	PM10 2008	NO2 2008	PM10 2008
Average annual concentration	0.10904	0.00712	0.11324	0.00740	0.10904	0.00712	0.11199	0.00732	1.00670	0.08651
(S D)	0.100	0.007	0.102	0.007	0.100	0.007	0.102	0.007	0.901	0.077
Minimum:	0.02560	0.002	0.02560	0.002	0.02560	0.002	0.026	0.002	0.239	0.022
Maximum:	1.070	0.070	1.070	0.070	1.070	0.070	1.070	0.070	9.010	0.733
Population weighted exposure	0.06267	0.00410	0.07752	0.00506	0.05622	0.00367	0.10408	0.00680	0.74742	0.06668

	COLLEFERRO		VITERBO		LATINA		ROCCASECCA (FR)	
	Landfill - Colle Fagiolara		Landfill - Le Fornaci		Landfill - Borgo Montello		Landfill - Cerreto	
	NO2 2008	PM10 2008	NO2 2008	PM10 2008	NO2 2008	PM10 2008	NO2 2008	PM10 2008
Average annual concentration	0.11655	0.00761	0.10601	0.00693	0.10072	0.00658	0.16316	0.00074
(S D)	0.135	0.009	0.126	0.008	0.090	0.006	0.119	0.001
Minimum:	0.01800	0.00117	0.002	0.000	0.017	0.001	0.013	0.000
Maximum:	0.837	0.055	1.230	0.081	0.920	0.060	0.798	0.004
Population weighted exposure	0.06488	0.00424	0.12122	0.00792	0.07667	0.00501	0.14963	0.00068

	COLLEFERRO Incinerator - Colle Sughero		ALBANO Incinerator - Cecchina		ROMA Gasification Plant - Malagrotta		SAN VITTORE (FR) Incinerator - San Vittore	
	NO2 2008	PM10 2008	NO2 2008	PM10 2008	NO2 2008	PM10 2008	NO2 2008	PM10 2008
Average annual concentration	0.06206	0.00224	0.01993	0.00257	0.04558	0.00297	0.11790	0.00770
(S D)	0.1	0.003	0.015	0.002	0.040	0.003	0.115	0.008
Minimum:	0.00791	0.000	0.001	0.000	0.011	0.001	0.011	0.001
Maximum:	0.515	0.019	0.092	0.013	0.377	0.025	0.874	0.057
Population weighted exposure	0.03243	0.00117	0.02545	0.00347	0.05993	0.00391	0.08964	0.00586

Figure 19. Incinerator San Vittore (Lazio).
PM10 concentrations (μg/m3) from dispersion model.

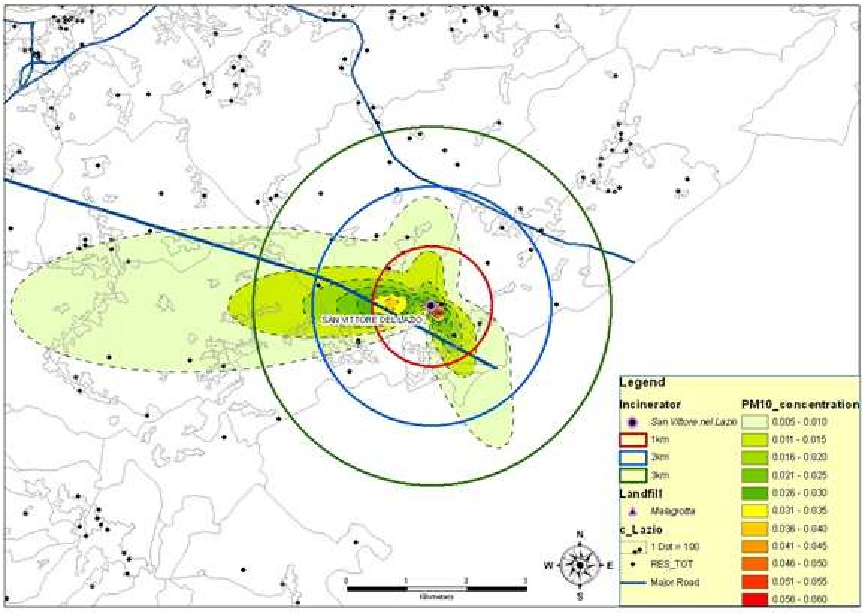


Figure 20. Landfill Malagrotta (Lazio).
PM10 concentrations (µg/m3) from dispersion model.

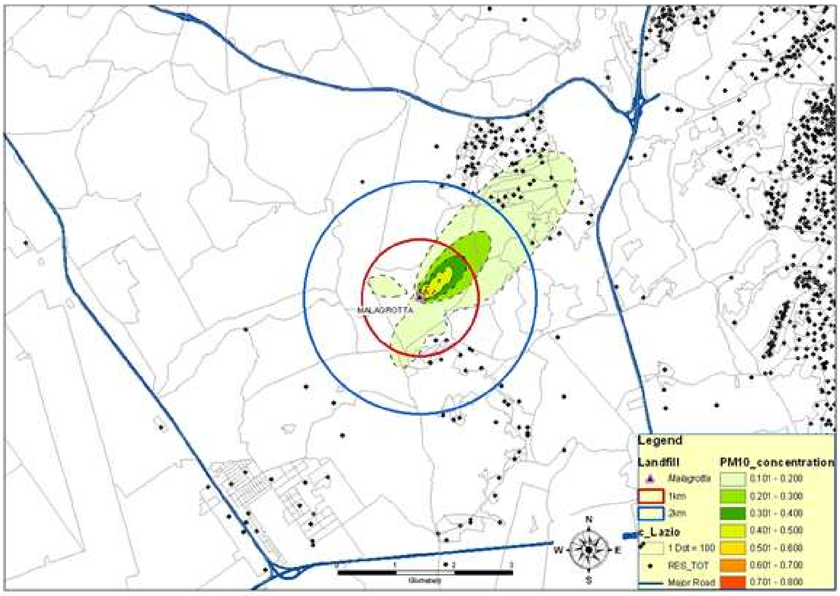
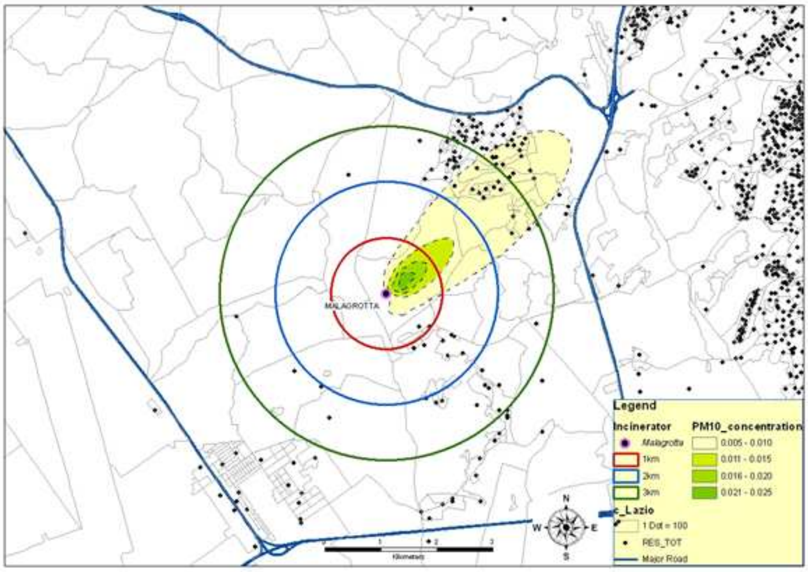


Figure 21. Gasification Plant Malagrotta (Lazio).
PM10 concentrations (µg/m3) from dispersion model.



6. <u>Quantification of the health impact: attributable cases</u>:

<u>Transport (workers):</u> An annual number of 243 occupational injuries were estimated, with 0.8 fatalities each year. Despite an occupational health programme was foreseen in the alternative scenarios, we could not anticipate the effectiveness of the program and therefore the injury rates considered were the same. In addition, it was difficult to predict changes in technology of the vehicle fleet. However the absolute number of accidents will decrease in the Green Policy because of the reduction of the manpower in the sector.

<u>Transport (population):</u> The impact of transport of waste on the population of Rome could be estimated in 561 (NO_2) and 14 (PM) Years of Life Lost (YLL) at baseline; the impact decreases to 50 and 1 (waste strategy) and to 29 and 0 (green policy), respectively.

MBTs: only small differences among scenarios in the number of people residing nearby MBTs were estimated. As a consequence, the prevalence of subjects with severe odours annoyance was constant (about 130 subjects) and the prevalence of people with respiratory symptoms attributable to the plants was about 500 subjects in all the scenarios.

Incinerators: as indicated, when compared to the baseline, a 60% increase in the number of people residing nearby incinerators was estimated with the waste strategy, whereas a 60% decrease was estimated with the green policy. The cumulative incidence of attributable cancer cases over the 35 year period was 7.5, 11.7and 2.5 in the three scenarios, respectively. A total of 10 YLL (NO_2) attributable to incinerators were estimated at baseline. The numbers increase to 15.9 YLL with the waste strategy and decrease to 9.6 with the green policy. The YLL attributable to PM were very small.

Landfills: the same number of people was residing nearby at baseline and with Waste strategy, whereas a decrease of 65% was observed with the Green policy. Low birth weight cumulative incidence was 8.3 newborns (baseline and waste strategy) and 2.8 in the green policy. The cumulative incidence of congenital anomalies was 0.3 individuals (baseline and waste strategy) and 0.1 in the green policy. The health impact as YLL was 17.9 (NO_2) estimated at baseline and with waste strategy and a decrease to 12.4 with the green policy. The prevalence of severe odours annoyance and respiratory symptoms assessed for residents at 200 meters, were 54 and 424, respectively, for the baseline and the waste strategy, whereas the numbers are lower (19 and 147) with the green policy.

Table 8. Health impact of waste management in Lazio according to policy scenarios: population and attributable cases.

		Baseline 2008	**Waste Strategy 2016**		**Green Policy 2016**	
Variable	Measure	n°	n°	% change over baseline	n°	% change over baseline
Transport						
Population involved (workers)		9633	10297	6.9	8358	-13.2
Occupational injuries	Annual Incidence					
Fatalities		0.8	0.9	6.9	0.7	-13.2
Major injuries		40.7	43.6	6.9	35.4	-13.2
Over 3 days injuries		201.6	215.5	6.9	174.9	-13.2
Total accidents		243	260	6.9	211	-13.2
Population involved (Rome residents)		2559005	2559005	0.0	2559005	0.0
YLL (NO2)	Cumulative Incidence	561	52	-90.6	29	-94.8
YLL (PM10)	Cumulative Incidence	14	1	-96.2	0	-97.9
MBT (n.plants)		**7**	**13**		**7**	
Population involved (0-0.2 km)		2345	2426	3.5	2353	0.3
Severe odour annoyance	Prevalence	127	131	3.5	127	0.3
Irritative respiratory symptoms	Prevalence	557	576	3.5	559	0.3
Incinerators (n. plants)		**2**	**4**		**2**	
Population involved (0-3 km)		23917	39284	64.3	8809	-63.2
Cancer cases	Annual Incidence					
2020	Annual Incidence	0.25	0.28	12.4	0.05	-79.9
2030	Annual Incidence	0.36	0.49	35.1	0.10	-73.8
2040	Annual Incidence	0.15	0.34	129.7	0.08	-42.1
2050	Annual Incidence	0.00	0.10	6672.0	0.02	1165.0
2016-2050	Cumulative Incidence	7.48	11.72	56.6	2.46	-67.1
YLL (NO2)	Cumulative Incidence	10.0	15.9	58.6	9.6	-4.6
YLL (PM10)	Cumulative Incidence	0.011	0.025	125.1	0.015	33.0
Landfills (n. plants)		**9**	**9**	0.0	**6**	-33.3
Population involved (0-2 km)		9929	9929	0.0	3444	-65.3
Low Birth weight (2016-2050)	Cumulative Incidence	8.28	8.28	0.0	2.81	-66.1
Congenital anomalies (2016-2050)	Cumulative Incidence	0.29	0.29	0.0	0.10	-66.1
YLL (NO2)	Cumulative Incidence	17.9	17.9	0.0	12.4	-30.6
YLL (PM10)	Cumulative Incidence	0.0	0.0	-6.7	0.0	-27.7
Population involved (0-200 m)		993	993	0.0	344	0.3
Severe odour annoyance	Prevalence	54	54	0.0	19	-65.3
Irritative respiratory symptoms	Prevalence	236	236	0.0	82	-65.3

6. <u>Quantification of the health impact: DALYs</u> :

Table 9. Health impact attributable to waste management in Lazio according to policy scenarios: Disability Adjusted Life Years (DALYs).

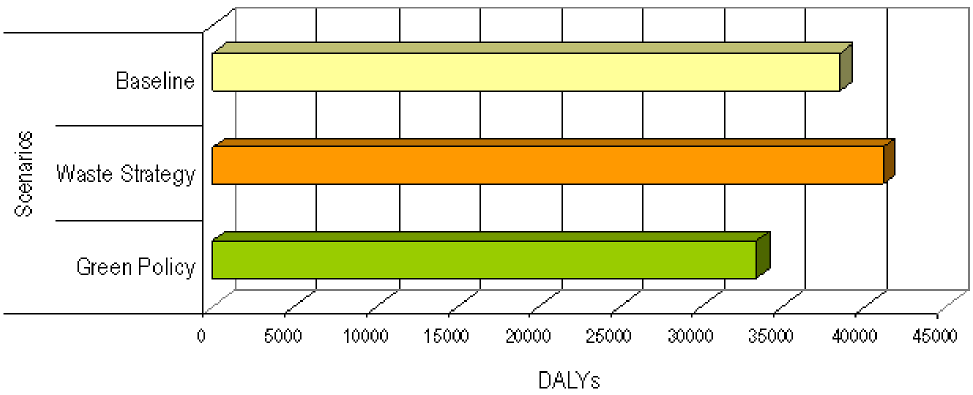
Variable	Baseline	Waste Strategy	% change over baseline	Green Policy	% change over baseline
	2008	2016		2016	
Transport					
Population involved (workers)					
Occupational injuries					
Fatalities	1069	1143	6.9	927	-13.2
Major injuries	11065	11828	6.9	9600	-13.2
Over 3 days injuries	26321	28136	6.9	22837	-13.2
	38454	**41107**	6.9	**33365**	-13.2
Transport					
Population involved (Rome 2001 residents)					
YLL (NO2)	560.7	52.5	-90.6	29.1	-94.8
YLL (PM10)	13.9	0.5	-96.2	0.3	-97.9
TOTAL	**575**	**53**	-90.8	**29**	-94.9
MBT (population involved 0-0.2 km)					
Severe odour annoyance	89	92	3.0	89	-0.1
Respiratory symptoms	1114	1152	3.4	1118	0.4
TOTAL	**1203**	**1244**	3.4	**1207**	0.3
Incinerators (population involved 0-3 km)					
Cancer cases	41	65	56.6	14	-67.1
YLL (NO2)	10.01	15.88	58.6	9.55	-4.6
YLL (PM10)	0.01	0.03	125.1	0.01	33.0
TOTAL	**52**	**81**	57.0	**23**	-54.9
Landfills (population involved 0-2 km)					
Low Birth weight (2016-2050)	70	70	0.0	24	-66.1
Congenital anomalies (2016-2050)	4	4	0.0	1	-66.1
YLL (NO2)	17.87	17.87	0.0	12.40	-30.6
YLL (PM10)	0.03	0.03	0.0	0.02	-22.7
Population involved (0-200 m)					
Severe odour annoyance	56	56	0.0	20	-65.3
Respiratory symptoms	1002	1002	0.0	348	-65.3
TOTAL	**1150**	**1150**	0.0	**405**	-64.8
TOTAL FOR ALL	41433	43634	5.3	35029	-15.5

Table 10. Health impact attributable to waste management in Lazio according to policy scenarios: summary of Disability Adjusted Life Years (DALYs).

		Baseline 2008		Waste Strategy 2016		Green Policy 2016	
Workers	Transport	38454		41107		33365	
		n	**%**	**n**	**%**	**n**	**%**
Resident Population	Transport	575	19.3	53	2.1	29	1.8
	MBT	1203	40.4	1244	49.2	1207	72.5
	Incinerators	52	1.7	81	3.2	23	1.4
	Landfill	1150	38.6	1150	45.5	405	24.3
	TOT	2979	100	2527	100	1665	100

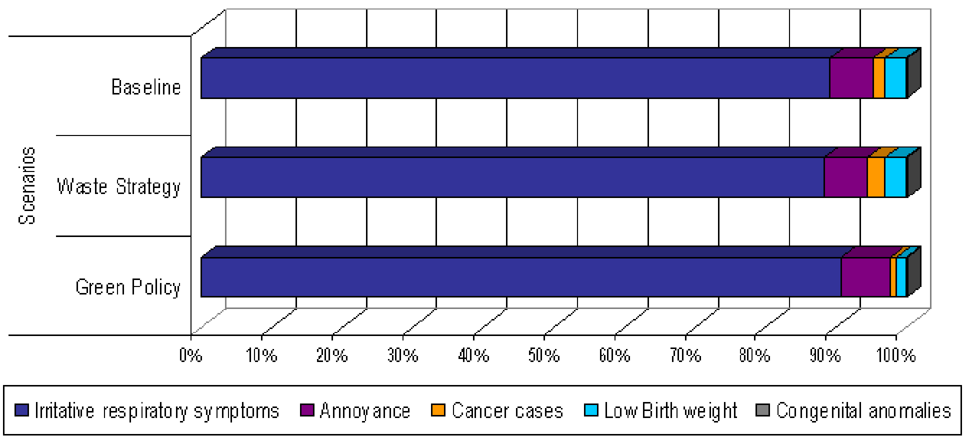
The most important health impact of waste management is occupational accidents responsible of about 40,000 DALYs for the baseline and the Waste strategy whereas the impact decreases to 33,000 DALYs with the Green policy.

Figure 22. DALYs from occupational injuries among waste workers



For the general population, a total of about 3000, 2500, and 1600 DALYs were estimated under the different scenarios, respectively. The largest contribution to DALYs for the general population is from respiratory symptoms (about 90%) and odour annoyance; while the contribution from the other health disorders is small.

Figure 23. DALYs by specific health disorders



As a consequence, when the relative contribution to DALYs is divided by management process (Figure 24), for the baseline the largest contribution to DALYs comes from landfills and MBTs, although also transport provide a 19% contribution. The decrease in DALYs with the waste strategy is mainly attributable to better transport while with the Green policy also the contribution from landfills decreases.

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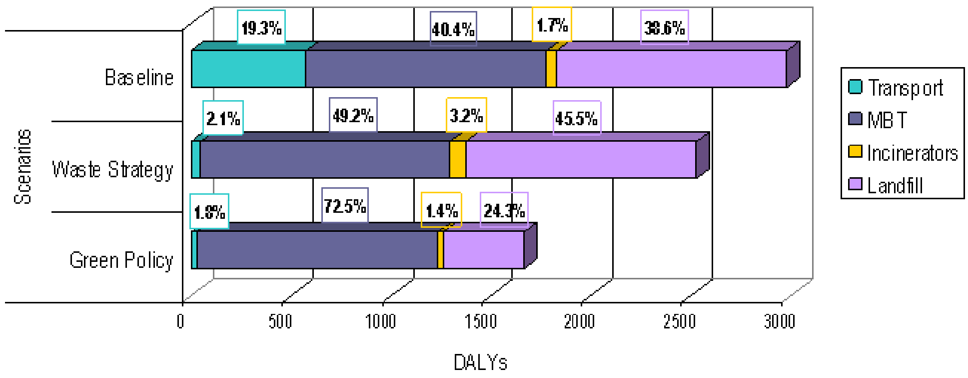
Figure 24. DALYs by scenario and waste management process (general population)



See also Tables 3-10.

See also Figures 3-24.
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<td>Implications</td>
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We found a moderate impact of waste management on environment and health when compared to other potential environmental factors, like traffic air pollution or second-hand smoke. However, a few results are worth to be pointing out.

1. The most important heath impact of waste management is occupational accidents related to the collection, load and transport of waste. This is an area of great importance as long as collection of waste is made along the streets/roads without a strong injuries prevention programme. Of course, we are confident that new technology will help in this respect. We could not evaluate the effects of these future potential changes and the uncertainties about our estimates on future injury rates and health consequence are large but we hope in the conservative way.

2. The possible role of transport of waste with highly polluting trucks is often neglected in the discussion of waste management related health problems. Our estimates at baseline indicate a relevant environmental impact for the city of Rome, especially for people living along roads with high trucks traffic. This environmental impact translates to a relative important health impact in terms of DALYs. Programs to change from high to low polluting vehicles are crucial in this respect.

3. A relevant health impact was estimated from landfills and MBTs with regards to respiratory symptoms and odour annoyance. This is not of surprise as the perception of these aspects is the basis for community concerns over waste management plants. There are large uncertainties over the effect estimates we provided as the exposure-response coefficients were derived from single studies conducted in the past and the generalizability may be low. Moreover, new technologies may provide an important improvement to limit aerosols, dispersions of endotoxins, and odour release. Therefore, the ability to predict for the future is limited. However, our approach indicates the need to provide a strong preventive effort in this area.

4. The environmental and health impact generated from traditional management plants like landfills and incinerators is limited due to the strict legislation on emissions. Therefore, the numbers of additional cases of cancer or congenital malformations for current and future exposures is low. Nevertheless, these plants are a matter of concern especially because of the health effects potentially generated
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from emissions of the past or because malfunctioning of the plants requiring frequent maintenance.

5. Significant improvement in the environmental and health impacts can be achieved with future strategies dedicated to waste reduction, recycling, clean transport, composting and waste treatment before the final destination (table 11 for a summary).

Table 11. Summary of the environmental and health impacts of waste management in Lazio according to policy scenarios.

Variable	Baseline 2008	Waste Strategy 2016		Green Policy 2016	
	n°	n°	% change over baseline	n°	% change over baseline
Total waste (mTons)	3.333	3.471	4.1	2.833	-15.0
Recycling/Composting	0.593	2.065	248.0	1.983	234.3
To be managed	2.740	1.406	-48.7	0.850	-69.0
Landfill without pretreatment	1.902	0.000	-100.0	0.000	-100.0
Collection and transport					
Total Kms travelled	9899592	6119120	-38.2	3511785	-64.5
PM emissions					
Total (Tons)	17.86	6.62	-63.0	4.13	-76.9
per inhabitant (grams)	3.213	1.190	-63.0	0.742	-76.9
People living close to plants					
Incinerators (0-3 Km)	23917	39284	64.3	8809	-63.2
Landfills (0-2 Km)	9929	9929	0.0	3444	-65.3
MBT (0-200 m)	2345	2426	3.5	2353	0.3
Total residents	36191	51639	42.7	14606	-59.6
Population weighted exposure					
NO2 from transport - u/m^3	0.02030	0.00186	-90.9	0.00103	-94.9
Attibutable cases (2016-2050)					
Occupational injuries	243	260	6.9	211	-13.2
Severe odour annoyance (prev)	180	185	2.4	146	-19.2
Irritative respiratory symptoms (prev)	793	812	2.4	641	-19.2
Cancer cases	7.5	11.7	56.6	2.5	-67.1
Low Birth weight	8.3	8.3	0.0	2.8	-66.1
Congenital anomalies	0.3	0.3	0.0	0.10	-66.1
Years of Life Lost					
Due to NO2	589	86	-85.3	51	-91.3
Due to PM10	14	22	57.9	0.3	-97.8
Disability Adjusted Life Years (DALYs)					
Workers	38454	41107	6.9	33365	-13.2
Population	2979	2527	-15.2	1665	-44.1

The health impact can be reduced up to 60-70% as predicted for the green policy. However, our findings suggest an important equity issue: there is a differential distribution by social class for people living close to management plants and the poorest sector of the population is more exposed. The same happens for occupational injuries among workers. Since the equity issue is not solved in relative terms even in the most radical Green strategy, more attention should be posed to this aspect in future waste management planning and operation.

Supporting information	
Supplementary materials	The following supplementary information are included: Annex 1. waste causal chain Annex 2. emissions model Annex 3. transport model Annex 4. cancer model Annex 5. glossary Excel file with tables
Glossary	See Annex 5 for additional suggested glossary items

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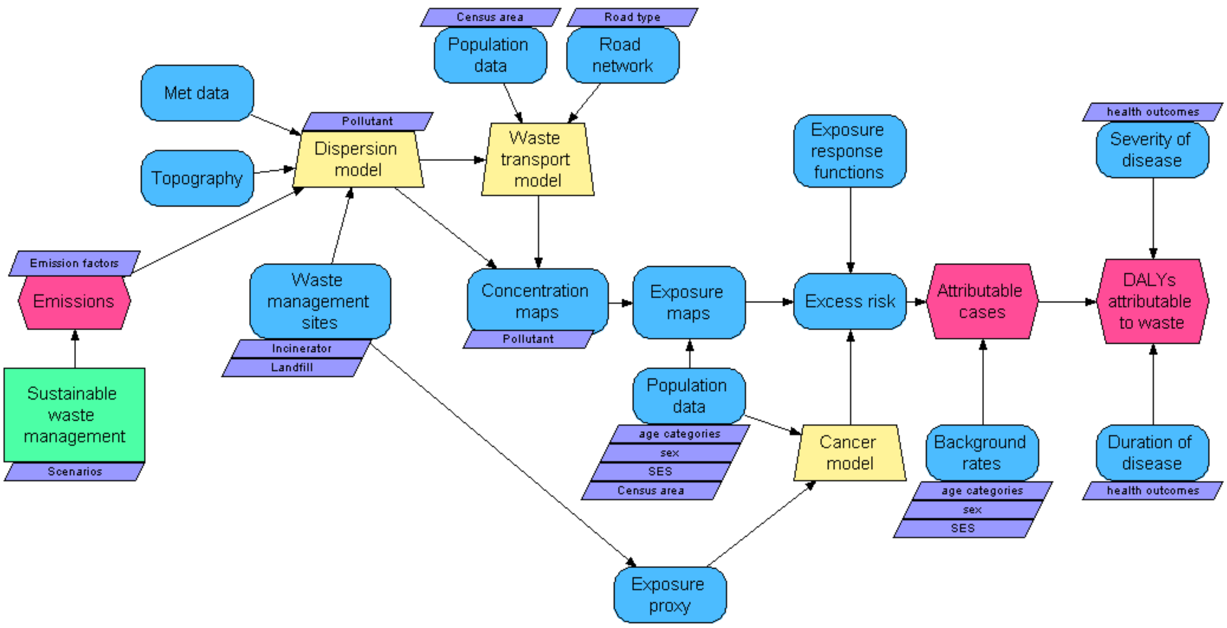
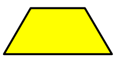
Annex 1. Municipal Solid Waste Causal Diagram



Name	Description
Decision	
	Two policy scenarios are compared with the baseline situation in 2008 to evaluate the impact of sustainable waste management. The Waste Strategy is the planned local policy on treatment of waste for the year 2016. The Green Strategy is , a more radical policy scenario operating in 2016.
Index	
Scenario's	amount of waste produced, collected and transferred to various treatment plants, according to the three policy scenario
Incinerators	Geographical coordinates of incinerators (or other combustion-based treatment plant) and plants characteristics: Year starting activity, chimney height, exit temperature, fumes capacity (Nmc/h) (for each line)
Landfills	Geographical coordinates of landfill sites, plus landfills characteristics: capacity per year, total volume, estimated area, biogas production, biogas capture (No/Flaring/capture for energy), year starting activity

MBTs	Geographical coordinates of Mechanical and Biological Treatment plants plus waste processed per year, estimated area, year starting activity
Emission factors	For each management process and for each type of pollutants, emissions per ton of treated waste See Annex 2. (Environs, 2004)
Pollutant	PM_{10}, SO_x, NO_x, metals, dioxins, PCBs
Census area	Total population as at the 2001 census, by census block of residence
Road type	Different road types – motorways, major roads (mainly A),local roads (B + minor), local roads (minor importance)
Age categories	Census population (2001) by five-year age classes (19): 0; 1-4; 5-9; 10-14; 15-19; 20-24; 25-29; 30-34; 35-39; 40-44; 45-49; 50-54; 55-59; 60-64; 65-69; 70-74; 75-79; 80-84; 85+
Sex	Males, Females
Socio Economic Status (SES)	Small-area (census block of residence) composite index based on 2001 census data as a measure of socioeconomic status (SES), classified in high, medium-high, medium, medium low, low on the basis of quintiles.
Health outcomes	Mortality, cancer, congenital malformations, newborns of low birth weight, respiratory symptoms, odour annoyance, occupational injuries.
Deterministic Variable	
Meteorological data	Yearly meteorological variables at the closest airport
Road network	TeleAtlas road network with info for different types of roads
Topography	Description of local surface shapes and features
Waste management sites	Plants for management and disposal of waste (landfills, incinerators, Mechanical and Biological Treatment (MBT) plants) operating according to the policy scenarios plus characteristics (e.g. location, stack height,gas velocity etc.)
Map of concentrations	Resulting GIS layers after dispersion models are applied. Assume concentrations are representative of exposures.
Map of exposure	Resulting GIS layers of pollutants after population data are applied
Population data	Census population 2001 stratified by age, sex and SES
Exposure response functions (ERF)	List of ERFs: Overall Mortality RR= 1.06 (95%CI=1.03-1.09) increase in mortality for 10 ug/m3 PM10

	RR= 1.06 (95%CI=1.04-1.08) increase in mortality for 10 ug/m3 NO_2 Morbidity -Cancer cases near incinerators (within 3 km): RR=1.035 (95% CI=1.03-1.04) (Porta et al, 2009). Such effect is scaled in the cancer model according to plant and population characteristics (see Annex 4) - Respiratory symptoms (cough on rising and during the day) near MBTs (200 meters) or landfills (200 meters): OR=3.18 (95% CI 1.24 to 8.36) which is equivalent to a Prevalence Rate Ratio= 2.25 (Herr et al, 2003) - Severe odour annoyance near MBTs (200 meters) or landfills (200 meters): 5.4% -Low birth weight near (2km) landfills: RR=1.06 (99% CI=1.052-1.062) (Porta et al, 2009) -Congenital anomalies near (2km) landfills: RR=1.02 (99% CI=1.01-1.03) (Porta et al, 2009). - Occupational injuries (per 100.000 workers in the waste industry) (HSE, 2009) - Fatality rate: 8.5 - Major injury accident rate: 423 - Over 3d injury accident rate: 2093 - Total accident rate: 2525
Exposure proxy	Exposure based on distance from the plants. The following distances have been considered. Incinerators: 0-3 km Landfills: 0-2 km MBTs: 0-1 km (or 0-2 km) Number of workers in the waste industry to estimate occurrence of occupational injuries
Excess risk	Difference between the incidence of a particular disease in subjects who were exposed to a specified risk factor(P(D|E)) and the incidence of the same disease among subjects who were not exposed (P(D| not E)). That is *ER* = P(D|E) - P(D| not E)

Background rates	country-level of prevalence/incidence of the disease
Severity of disease	Severity weights (adapted from Mathers et al, 1999) -Mortality = 1 -Cancer =0.44 -Respiratory symptoms = 0.08 -Low birth weight = 0.106 -Congenital anomalies = 0.17 -Severe odour annoyance = 0.03 - Occupational injuries - Fatality = 1 - Major injury = 0.208 - Over 3d injury = 0.10
Duration of disease	Duration of diseased health state (years) -Cancer = 12.6 -Respiratory symptoms = 1 (prevalence) -Low birth weight = 79.6 -Congenital anomalies = 79.6 -Severe odour annoyance = 1 (prevalence) - Occupational injuries - Major injury = 37.3 - Over 3d injury = 37.3
External Model 	
Waste transport model	Waste transport model uses information on waste generation capacity, road network and types of road, storage bins and collection vehicles to estimate the waste road flow (Annex 3).
Dispersion model	ADMS-Urban predict concentration of pollutants
Cancer model	Estimates excess cancer risk over time according to the characteristics of the incineration plant, time since first exposure and time since cessation of exposure (annex 4).

Indicator	
Emissions	Total estimated emissions of pollutants according to the policy scenarios.
Cases of disease attributable to the waste policy	Calculation of attributable cases 1. $AC = Rate_{unex} * ER * Pop_{exp}$ 2. where AC = the attributable cases 3. $Rate_{unex}$ = background prevalence/incidence rate in the general population 4. ER = excess risk in the exposed population (relative risk – 1) 5. Pop_{exp} = number of exposed subjects
DALYs	Disability Adjusted Life Years attributable to the waste treatment policy Calculation for DALYs = AC * D * S *Cases of disease attributable to the waste policy * Duration of disease * Severity of disease*

The entire model (causal diagram) is run once for each of the three scenarios: baseline, waste strategy, green policy, then the results are taken to evaluate predicted DALYs attributable to changes in waste policies.

References

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Herr CE, Zur Nieden A, Jankofsky M, Stilianakis NI, Boedeker RH, Eikmann TF. Effects of bioaerosol polluted outdoor air on airways of residents: a cross sectional study. Occup Environ Med. 2003 May;60(5):336-42.

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Victorian Government Department of Human Services. 2005 Victorian burden of disease study – mortality and morbidity in 2001. Melbourne: Public Health Group, Rural and Regional Health and Aged Care Services Division. Victorian Government Department of Human Services. Melbourne Victoria, 210 pp..

Porta D, Milani S, Lazzarino AI, Perucci CA, Forastiere F. Systematic review of epidemiological studies on health effects associated with management of solid waste. Environ Health. 2009 Dec 23;8:60.

Annex 2. Emissions model. Quantification of emissions from waste management processes

The total amount of MSW produced is divided according to its management destination. Some treatment processes produce an amount of residual materials per amount of MWS, depending on the kind of facility. Such residuals enter again into the flow of MSW management and therefore the actual amount of MSW treated in the facilities is different from the amount of MSW initially directed to them. Data on these residuals have been collected and included in the calculations. It has been assumed that MBT (mechanical biological treatment) facilities produce about 35% of material to be incinerated and 46% of material to be landfilled; in addition, it has been assumed that the residuals to be landfilled from incinerators are about 15% of the material originally delivered. Because this data was developed under circumstances which are considered as "standard" for MBT facilities and incinerators, and considering that consistent values have been reported in the descriptive waste reports of, we have a high level of confidence in these assumptions.

We apply the emission factors in Table 1 for small scale incinerators and Table 2 for other processes (grams per Tonne) to estimate the process-specific and total air emissions of the pollutants at the area level. While we have a high level of confidence for the emission factors related to incinerators (as they are based on measured values for Italy and the UK), we have only moderate confidence in the values for the other technologies because they were estimated for England and extrapolated to the other countries. The results should be divided by the total population of the area to obtain emitted toxicants per inhabitant. All the calculations are performed using an Excel spreadsheet (waste emissions calculator). The spreadsheet allows performing calculations under different scenarios.

Table 1. Emission factors (grams per tonnes of municipal waste) from incinerators in three countries in 2001.

Pollutant	Emilia-Romagna *		Italy
	1996	2003	2001**
PM	28	22	25
Cadmium	0.05	0.02	0.04
Nickel	1.36	0.10	0.73
Arsenic	0.026	0.040	0.033
Mercury	0.27	0.13	0.20
NO_x	1598	1290	1444
SO_2	128	73	101
HCl	129	31	80
HF	2.4	2.8	2.6
Dioxins/Furans	1.2E-04	3.2E-05	7.6E-05
PCBs	3.0E-05	3.0E-05	3.0E-05

* Measured values from eight plants in Emilia Romagna

** Italian emission factors for 2001 estimated as average of 1996 and 2003 data from Emilia-Romagna

Table 2. Emission factors (grams per tonnes of municipal waste) from management processes* in the three countries in 2001.

Pollutant	MBT	Anaer. Digest.	Pyro./gas.	Landfill/engines	Landfill/flaring	Transport
PM	0	0	12	5.3	6.1	1.3
Cadmium	0	0.0001	0.0069	0.0071	0.0071	0
Nickel	0	0.0003	0.04	0.0095	0.0095	0
Arsenic	0	0.0005	0.06	0.0012	0.0012	0
Mercury	0	0.0006	0.069	0.0012	0.0012	0
NO_x	72.3	188	780	680	75	31
SO_2	28	3	52	53	90	0.11
HCl	1.2	0.02	32	3	14	0
HF	0.4	0.007	0.34	3	2.7	0
VOCs	36	0	11	6.4	7.6	5.1
Cl-VOCs	0	0.0004	0	2.77	2.63	0
Benzene	0	0	0	0.00006	0.00006	0.0029
Dioxins/Furans	4.0E-08	0	4.8E-08	1.4E-07	5.5E-08	3.8E-11
PCBs	0	0	0	0	0	0

* Emission factors for incinerators are presented in table 1.

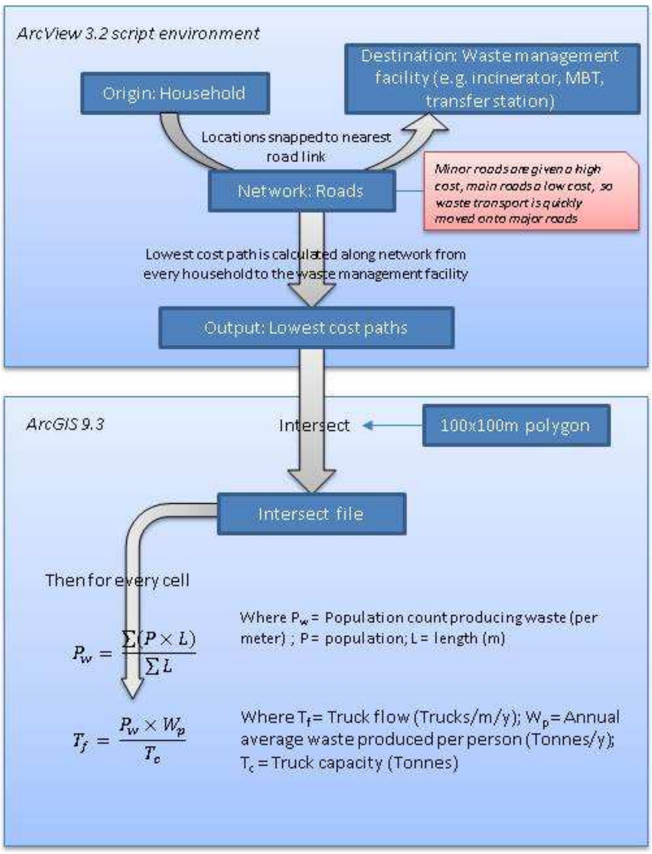
Adapted from Enviros (2004)

The emission factors for transport in 2016 have been modified assuming that the original emission factors were derived for Euro2 heavy diesel engines (NO_x = 7g/km PM = 0.15g/km) and that the Euro3 emission factors (NO_x = 5g/km PM = 0.13g/km) had to be applied for 2008 and the euro5 emission factors (NO_x = 2g/km PM = 0.02g/km) had to be applied for 2016.

Annex 3. Waste transport methodology

Concentrations arising from waste transport are modelled using a purpose build GIS model. The waste transport model uses information on waste generation capacity, road network and types of road, storage bins and collection vehicles to estimate traffic flow attributable to waste collection and waste transport. A shortest cost path analysis constructs routes from collection points to waste management sites giving high costs to minor roads and low costs to major roads. Total amount of waste collection vehicles is then calculated and gridded to a 100x100m raster. A kernel file, which is modelled in ADMS-Urban and reflects dispersion of traffic emissions around a 100x100 grid cell, is then used in the ArcInfo Focalsum function to create a modelled concentration grid.

The first step is to estimate the traffic flow (truck flow). A script in ArcView3.2 (see Figure 1) calculates the lowest cost path between origin (households) and destination (waste management facility). The lowest cost path is then intersected with a 100x100m polygon in ArcView 9.3 and further calculations, using statistics on waste generation per household and truck capacity, generates the truck flow per 100x100m polygon.



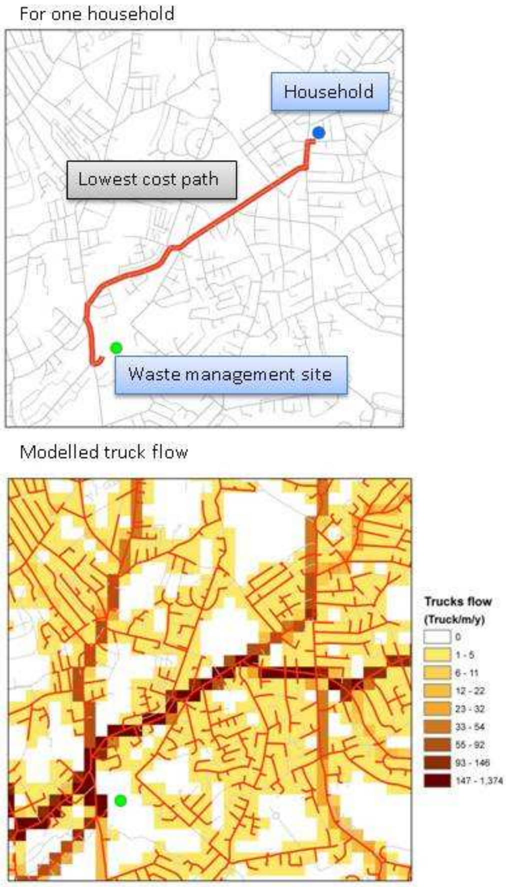


Figure 1 Waste Transport methodology- step 1

The second step is to convert these truck flows into concentrations grids.

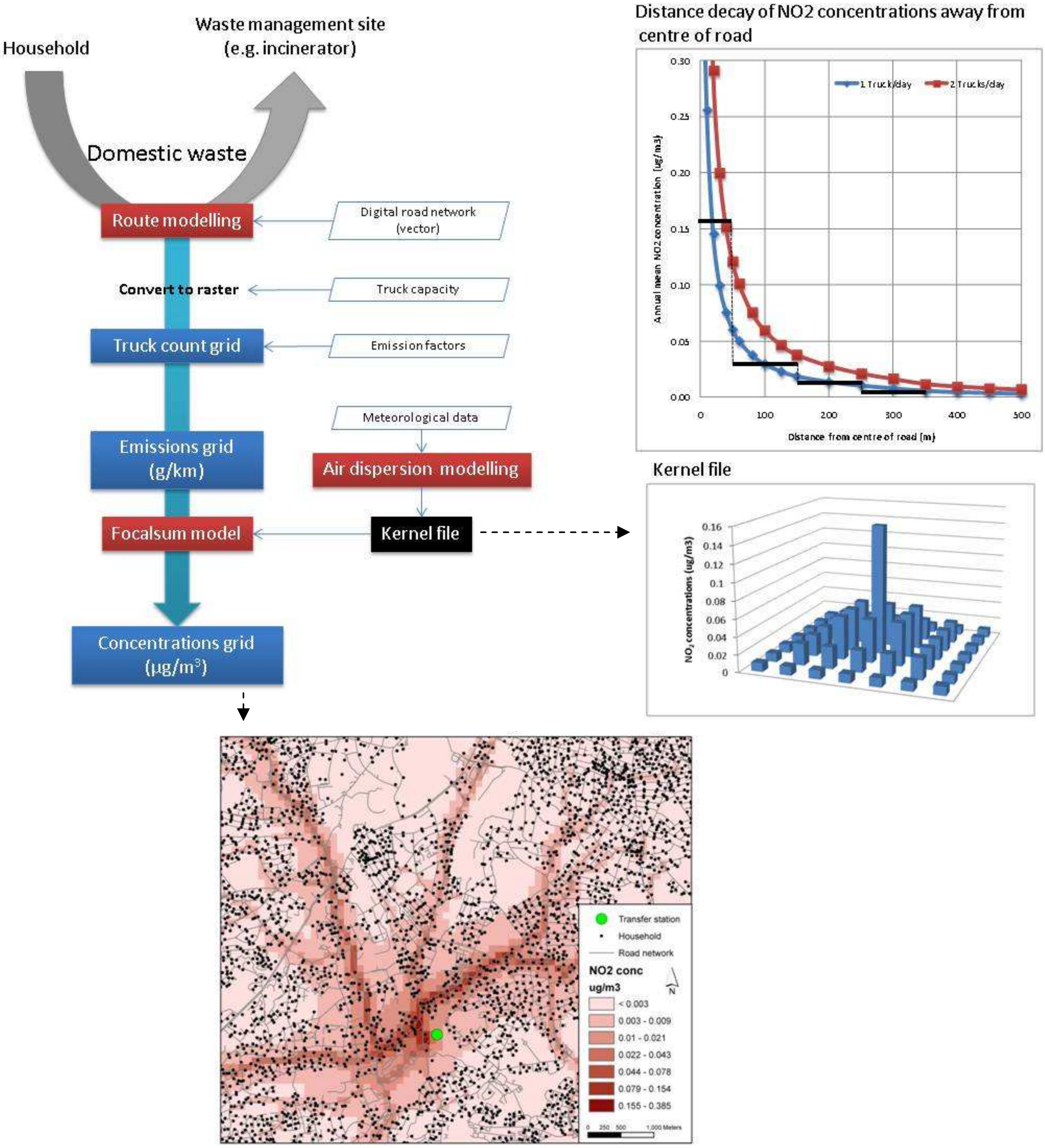


Figure 2 Waste transport methodology – step 2

Figure 2 shows how the truck flow polygon file is converted into a raster and by applying emission factors is turned into an emission grid. A kernel file, which is produced in ADMS-Urban, is then used to convert emissions into concentrations.

This remainder of this annex describes step-by-step the the functions and caculations performed within ArcView.

1. Network analysis

First a new field 'cost' is added to the TeleAtlas road network and roads are reclassified according to Table 1. The purpose of this is to try and replice the real world by moving trucks on main roads as soon as they have collect the waste.

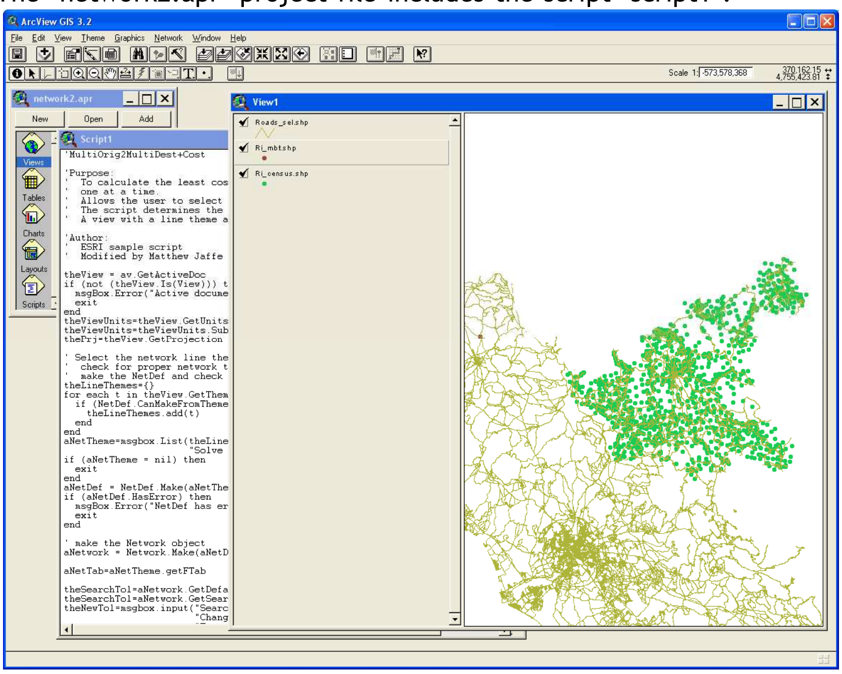
Table 1 Definitions of cost based on the FRC field:

FRC (Functional Road Class)	Description	Cost (times length)
0	Motorways	1
1+2+3	Major roads (mainly A)	2
4+5+6	Local roads (B + minor)	3
7+8[1]	*Local roads (minor importance)*	*4*

[1] these roads were left out of the road shape file in order to reduce the number of road segments so the ArcView script could run.

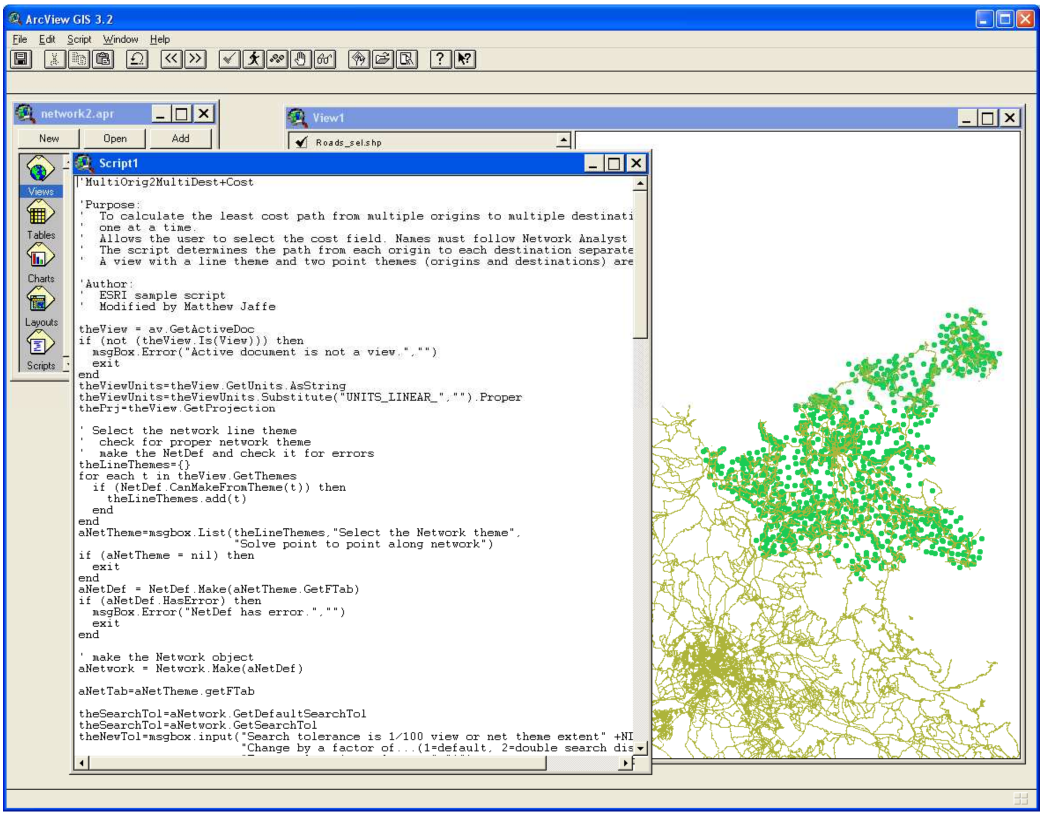
1. Add new 'COST2' field with 1, 2 or 3 for the different road types
2. Add new 'COST' fiels; multiply 'COST2' times 'LENGHT'

Run the script in ArcView3.2. The 'network2.apr' project file includes the script 'script1'. The origin file, destination file and the road network (resp. ri_census.shp, ri_mbt.shp and roads_sel.shp in this example)need to be added to the view.



There will be occasions where you rather than one MBT there are two MBTs to transport waste to. Apply the same method as above, but now you will have costs calculated from every census block to two MBTs. To decide which route to choose, we apply the prossimity criteria.

Then open ‘Script1’ and click 



The following windows will appear in which the following selections are made:

- Window 1: Solve point to point along network. Select Roads_sel.shp and click OK
- Window 2: Feature location theme. Use the default and click OK
- Window 3: Select a Cost. Select ‘Cost’ and click OK.
- Window 4: Solve point to point along network. Select the origin theme: select ri_census.shp and click OK.
- Window 5. Solve point to point along network. Select the destination theme: select ri_mbt.shp and click OK.
- Window 6: Origin theme. Select ‘Cod_ss’ and click OK.
- Window 7: Destination theme. Select ‘Id’ and click OK.
- Window 8: Specify a output filename and saving folder. Save your output file and click OK.

The program will now run.

First run: find shortest cost path between centroids of census blocks and MBT

Origin file: *ri_census.shp*, destination file: *ri_mbt.shp*, route network: *roads_sel.shp*. The output saved as *path_ri_c_mbt.shp* (this will contain calculated short paths from every cencus block centroid to the MBT).

2 Calculating concentration maps

The rest of the analysis is done in ArcMAP (ArcView9.3).

To check for how many of the census blocks a shortest cost path was calculated:

1. Select from *path_ri_c_mbt.shp* where 'COST' <> 0. save as *path_ri_c_mbt.shp*

We need to get paths for the left overs census blocks and the easiest way to do this, is to attribute for each of these, the nearest census block with a calculated cost path.

1. Select from *ri_census.shp* the census with cost <>0 and save as *ri_c_cost.shp*
2. Select from *ri_census.shp* the census with cost =0 and save as *ri_c_nocost.shp*
3. Join data from another layer based on spatial location *ri_c_nocost.shp* ("COD_SS" variable) to *ri_c_cost.shp* ("COD_SS" variable), save as *ri_c_nocost_join.shp*

We need to get paths for 39 left overs and the easiest way to do this is to map the census blocks and look for each of these 39 for the nearest census block with a calculated cost path. We then copy that route to a new shape file, the extra road shape file. So for instance:

1. Open the Editor and start editing the extra road shapefile.
2. You can now, one by one, look at one of the missing census blocks, choose the nearest census block with a path, select this path from path_ri_c_mbt.shp, select 'copy' from the EDIT drop down menu, and then select 'paste'; the selected route should now have been copied to the new road shapefile. Make sure you add fields to this extra road shapefile with a reference to the census block ('COD_SS')

You have now the outputs; *paths_ri_c_mbt.shp* with all shortest cost path calculated. Then you have to do the following:

1. Intersect *paths_ri_c_mbt.shp* with 100x100m grid – *lazio_poly.shp* to create *paths_ri_c_mbt_int.shp*.
2. Update the 'LENGTH' field
3. Join the population living in each census block to *paths_ri_c_mbt_int.shp* to create *paths_ri_c_mbt_int_pop.shp*.
4. Calculate 'length' x 'nr_res' = 'pop_lgth' for every record.

The next step is to calculate the waste produced in every grid cell. This can be done as follows:

1. Open the *path_ri_c_mbt_int_pop.dbf* file use Summarize to calculate the sum of 'pop_lgth' and sum of 'length' for every LAZIO_P_.
2. In the resulting pivot table calculate 'pop_lgth_sum' / 'length_sum' to get 'popwaste_m' which is the number of pop producing waste which is transported per m within the 100x100m grid square.
3. every person in RI. produces 0.25 kT[1] of waste per year, so multiply 'popwaste_m' x 0.25 to get 'waste_m' which is kT of waste transported per meter in every 100x100m grid square
4. Now assume that a waste collection truck carries 8 Tonnes of waste, so calculate 'waste_m' / 8 to get 'truck_m' which are the number of trucks per meter per year.

5. Then multiply by 2 to get both the directions to get ‘trucks_m_y’.
6. This number we can then multiply with the emission factor of PM10 and NOx for trucks to get to emissions_y (e.g. NO_2 emission factor for HGV at 40km/h from ADMS-Urban = 5.233 g/km). So NO2_em_y = truck_m_y * 5.233
7. NO_2 emission (g/y) is calculated by NO2 emission divided by length of the road / 1000: NO2_em_y * (length_sum / 1000). Now we have the emission for the whole 100x100m grid square per year – so g/10000m2/y
8. To get to g/m2/s we need divide by 10000 to calculate the amount of NO_2 produced for every m2 in 1 year (g/m2/y). Then divide by 365*24*60*60 to calculate the amount of NO_2 produced for every m2 in 1 second (g/m2/s). So NO2_em = NO2_em_gy / (365*24*60*60).

[1]For this example I assume that every resident in Lazio produces 0.25kT of waste per year (calculated from your file: sum of waste/sum of res).

After this you will notice that the values are getting really small, sometimes 10e-12. That’s why before exporting you need to multiply the value times 10e+12, this so it we can actually create a grid for it.

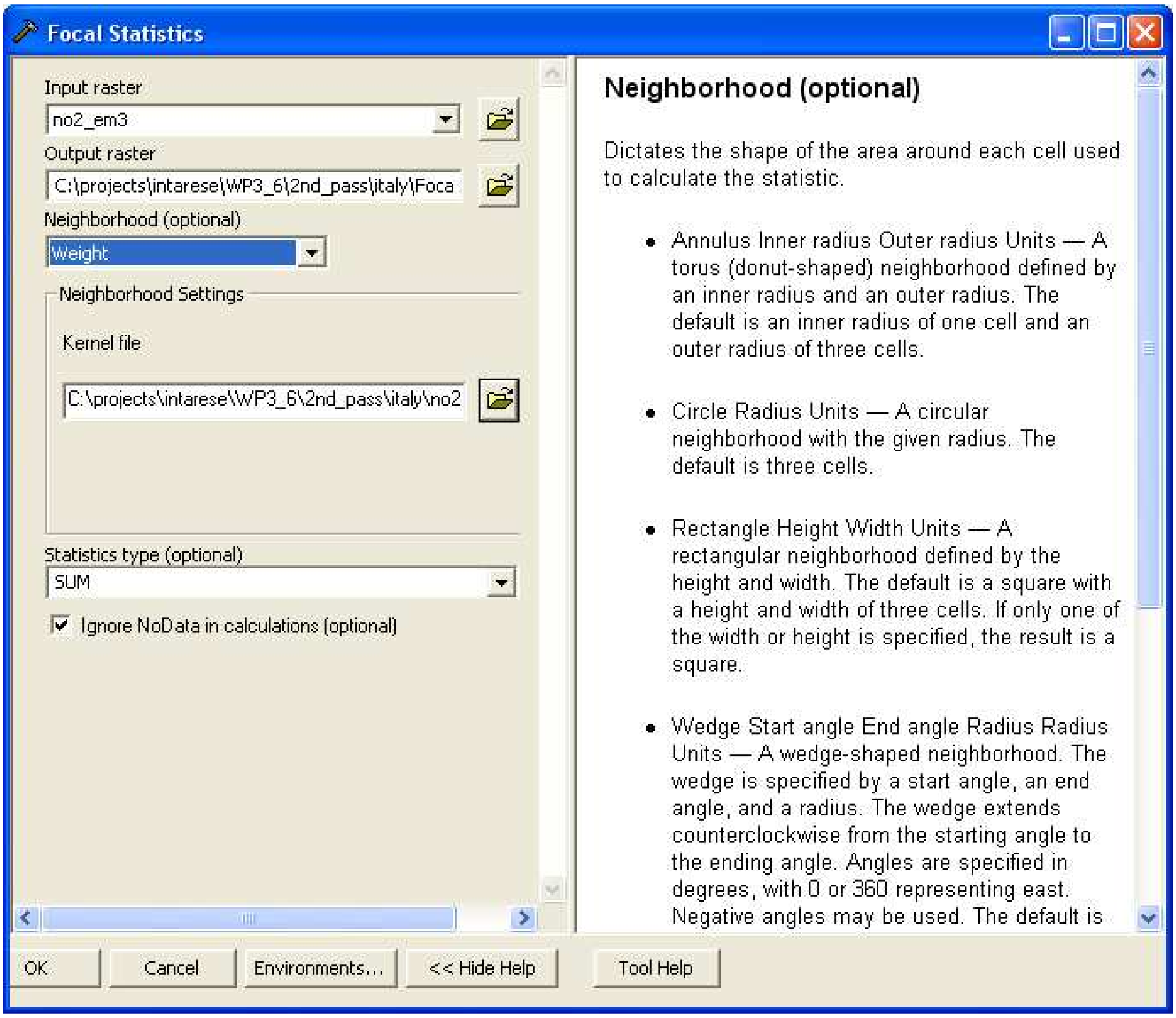
1. add NO2 like floating type and multiply the value NO2_em times 10e+12.

Now link back to *Lazio_poly.shp* (join on the field: LAZIO_P_) and convert back into a grid (using Spatial Analyst menu > Convert>Features to Raster, choose grid size = 100).

We now have our emission grid.

To get NO2 concentration you need divide back by 10e+12 (using Spatial Analyst menu>Raster Calculation).

I created a kernel file (NO2_KERNEL.TXT) which we can apply to the emission grid to get NO2 concentrations. This can be done with the ArcToolbox>Spatial Analyst>Neighborhood>Focal Statistics:


Focal Statistics
Input raster
no2_em3
Output raster
C:\projects\intarese\WP3_6\2nd_pass\italy\Foca
Neighborhood (optional)
Weight
Neighborhood Settings
Kernel file
C:\projects\intarese\WP3_6\2nd_pass\italy\no2
Statistics type (optional)
SUM
Ignore NoData in calculations (optional)
Neighborhood (optional)
Dictates the shape of the area around each cell used to calculate the statistic.
Annulus Inner radius Outer radius Units — A torus (donut-shaped) neighborhood defined by an inner radius and an outer radius. The default is an inner radius of one cell and an outer radius of three cells.
Circle Radius Units — A circular neighborhood with the given radius. The default is three cells.
Rectangle Height Width Units — A rectangular neighborhood defined by the height and width. The default is a square with a height and width of three cells. If only one of the width or height is specified, the result is a square.
Wedge Start angle End angle Radius Radius Units — A wedge-shaped neighborhood. The wedge is specified by a start angle, an end angle, and a radius. The wedge extends counterclockwise from the starting angle to the ending angle. Angles are specified in degrees, with 0 or 360 representing east. Negative angles may be used. The default is
OK
Cancel
Environments...
<< Hide Help
Tool Help

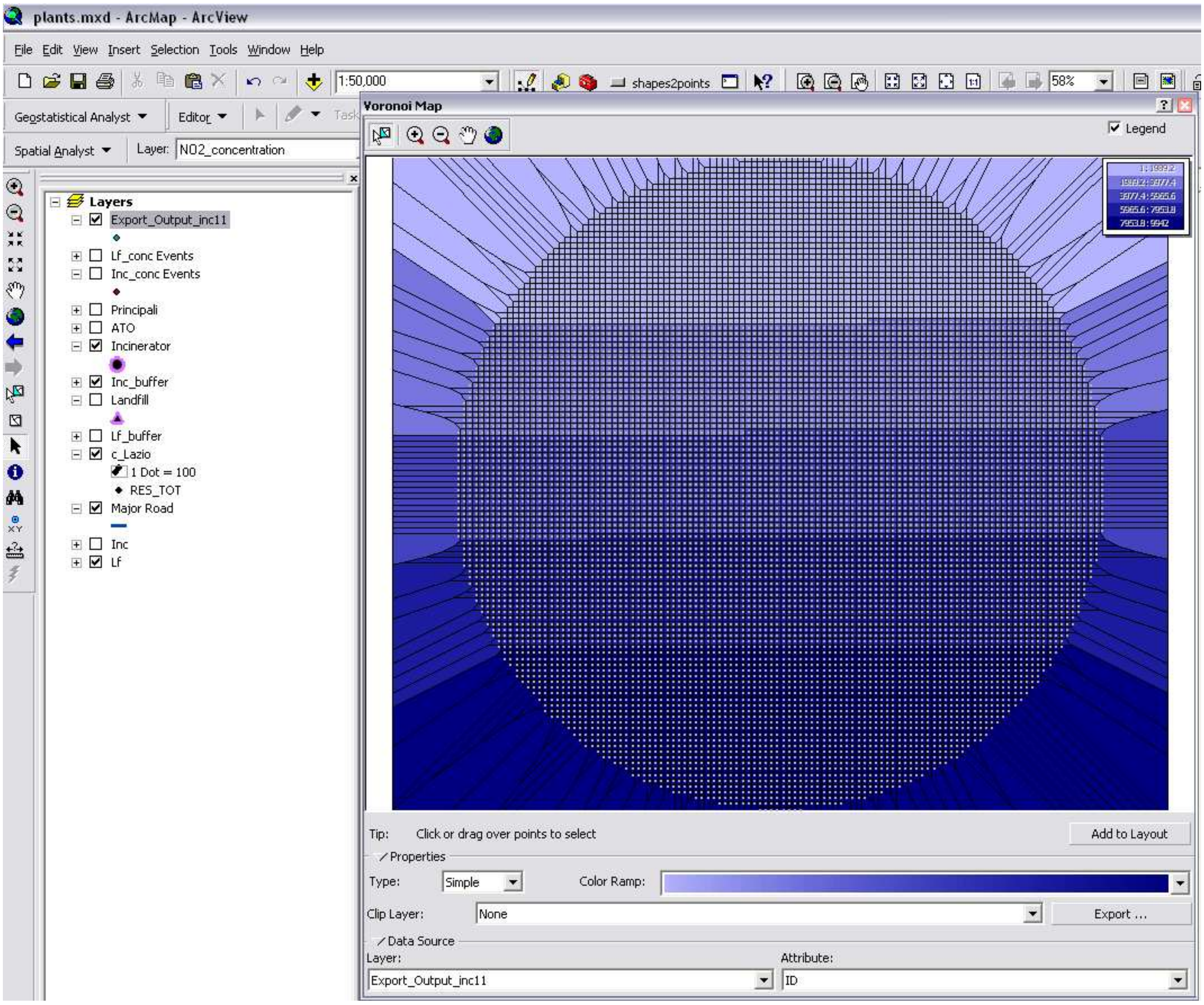
Population Weighted Exposure

Use the result from the dispersion modelling. The x and y coordinate are calculate from the incinerator stack or landfill flare coordinate, which for modelling purposes was put to 0,0. To convert the coordinates back into the State coordinate system, add X and Y variable, as double type, and for each incinerator/landfill calculate:

X = X_utm33n + XCOORD

Y = Y_utm33n +YCOORD

1. dislpay XY data to create *inc_conc Events.shp*
2. use Geostatistical Analyst Menu > Explore data >Varonoi map.



3. In the screen below select the **layer** (*inc_conc Events.shp*) and for **Attribute** use **ID**. Press **Export** to export the new polygon shapefile. Save as *Varonoi_inc.shp*

4. Next we need to get the concentrations attached to this polygon shapefile. This can be done by right using ArcToobox > Analyst Tools > Overlay > Spatial Join ("ID" variable) to *inc_conc Events.shp* ("ID" varialble). Save as *Varonoi_inc_SpJo.shp*

5. The next thing is create a 3km buffer around the incinerator (2km buffer around the landfill) and intersect that with *Varonoi_inc_SpJo.shp* . This way you are only left with what you are interested in. save as *Varonoi_inc_SpJo_clip.shp*

6. Now you can intersect the *Varonoi_inc_SpJo_clip.shp* with the census block shape file (*c_Lazio.shp*) with the RES_TOT attribute.

   save as*Varonoi_inc_SpJo_clip_int.shp*

7. do your new_area calculation and new_pop attribute calculate like new_pop = ((RES_TOT*new_area)/shape area).

8. then calculate the population by cell (100 x 100 metres). Use ArcToobox >Data Management Tools > Generalization > Dissolve. Dissolve field by ID NOX PM10 CO n° (number of incinerator) and sum new_pop attribute.

Save as *Varonoi_inc_SpJo_clip_int_Dis.shp*

Now you have the population by cell. And you are able to calculate the population weighted exposure. This can be done as follows:

1. open attribute table and Add NOX_pop = NOX * sum_new_pop, and Add PM10_pop = PM10 * sum_new_pop
2. Summarize select as fiel to summarize "n°" variable and sum "SUM_new_pop" ; "NOX_pop" ; "PM10_pop". Save as Inc_summarize.

Then we can finally calculate the

Pwe NOX = Sum (NOX * new_pop) / pop_tot

Pwe PM10 = Sum (PM10 * new_pop) / pop_tot

ANNEX 4 ESTIMATING ATTRIBUTABLE CANCER INCIDENCE AROUND INCINERATORS

Rationale

1. The basic formula to compute the number of cancer cases attributable to an incinerator is:

   AC = Rateunex * ER * Popexp

   where AC = the attributable cancer incidence

   Rateunex = background incidence rate in the general population

   ER = excess risk in the exposed population (relative risk – 1)

   Popexp = number of exposed people

2. We have relative risks calculated only for an arbitrarily defined exposed population (e.g. in terms of distance from an incinerator, Elliott et al.1996). Although the possibility to inference causality from these studies is limited (due to limitations of the studies discussed above), these estimates are the unique starting point for our assessment.
3. Once we have assumed that there is a relationship between living near incinerators and cancer incidence, we may suspect that the excess risk is not constant over time, but varies for a specific individual of the population at a give age and specific time as a function of various characteristics: level of attained cumulative exposure, latency since first exposure and latency since cessation of exposure (if any).
4. We therefore need to assume a theoretical model of cancer occurrence and to impute the varying excess risk around different incinerators, as a function of the different characteristic of the plant and of the nearby population.

Assumptions

1. Model of carcinogenesis. We do not have clear scientific data about the carcinogenic model underlying the association between living close to the plants and occurrence of cancer. We may assume here that the model that better fit our purpose is the most studies one that relates cigarette smoking with lung cancer. Under the multistage theory of cancer proposed by Armitage and Doll (Armitage and Doll, 1958), Doll and Peto (1978) indicated that the excess relative risk of lung cancer is a function of attained age together with a complex dependency related to age at starting, duration and intensity of smoking and time since quitting. Various attempts have been made to validate the model using data from real long term cohorts (Hazelton et al. 2005; Schollnberger et al. 2006). Although the results of these studies do not provide a uniform response regarding the role of each factor (Hornsby et al. 2007), and the approach may be seen as a simplification, it has the advantage to provide a template for addressing other exposure-response relationships (Siemiatycki, 2005). It is clear that this model that is mostly applicable to solid cancers of epithelial origin. The approach could be different for hematological or soft tissues cancers or for childhood cancer. Finally, the model that we assume is multiplicative in nature, namely that the excess risk is a multiplicative function of the baseline risk.
2. Uniform excess risk in the area within 3 Km. We may assume that on a given year the excess risk cross all exposed areas around a given incinerator in the study (3 km) is equal to that derived from the scientific literature with corrections depending on several factors referenced above.
3. Reference Excess Risk (RER). We may assume as reference that the value of 3.5% (95%CI: 3-4%) excess risk reported in the paper by Elliott et al (1996) reflects the additional risk of total cancer incidence for a population living within 3 km from an incinerator exposed for a duration of 20 years at the levels of contamination that were present in the period 1960-1980. We can call this value Reference Excess Risk (RER). In fact, all the 72 incinerators studied in the Elliott's paper did start operation before 1976, the follow-up was conducted during 1974-1986 (1974-1987 for Wales and 1975-1987 for Scotland), and the effect estimate was given considering 10 years of latency for solid cancers.

4. Exposure levels vary with time. We may assume that in subsequent years after 1980, due to technological improvements and as results of national and European laws, the emissions from incinerators have been reduced. For instance, measured particulate matter emissions from one incinerator in Italy (Modena) where 0.19 g/s in 1980-1989 (two lines), 0.0347 and 0.376 g/s in 1995-1996 (two lines), 0.0196, 0.0273 and 0.104 g/s (three lines) in 1997-2002, and 0.0081, 0.0101, and 0.013 g/s (three lines) in 2003-2006. On the other hand, emission limits in the UK were reduced through legislation from 460 mg/m3 (1968) to 200 mg/m3 (1983) to 30 mg/m3 (1989/1990) and finally to 10 mg/m3 in 2000. On the basis of these data, we can assume that if the exposure level was 1 before 1980, it was 0.8 in 1980-1989, 0.2 in 1990-2000, and 0.05 after 2000. In other words, we are assuming that the exposure levels during the eighties were lower (0.8) that during the seventies, during the nineties were fourfold lower, and in more recent times they were twentyfold lower that the seventies. Of course, these assumptions may be varied in sensitivity analysis.
5. Calculation of cumulative exposure. We need to recognise that at a given age of a person, the best way to summarize the exposure experience is to calculate cumulative exposure (CE) as the sum of the exposure contribution during the different periods. The analogues for cigarette smoking are pack-years. For example, a person aged 60 in 2001, living nearby an incinerator opened in 1980 and still running in 2001, will have over the period 1980-2001 a CE of 10.25 (8+2.2+0.05=10.25, i.e. 10 years at exposure 0.8 in 1980-1989, 11 years at exposure 0.2 in 1990-2000, and one year in 2001 at exposure 0.05).
6. Latency since first exposure and latency since exposure cessation. Finally, latency since first exposure is a relevant issue, especially if a long time for the evaluation is to be considered. For most solid cancers, there is some cancer expression only several years after first exposure to carcinogens and the full effect is appreciable only after 20 years (as indicated above, latency may be shorter for non solid cancers). In our case, we assume that the effect of the exposure to a given incinerator will be appreciable only after some years from first exposure, the peak will be reached after 20 years and it will be constant up to 40 years, then it will start to smoothly decline approaching 0 after 70-80 years. On the other hand, if the exposure is removed, as in the case of smoking cessation, the risk declines as a function of the time since cessation. We may assume that the excess risk will smoothly decline soon after cessation of exposure.
7. For practical reasons, we need to assume that the population selected on a given year has been always living close to the plant and it size and age composition will be constant during the period of the evaluation.

Calculations

1. Time and age. For a specific age class (a_i) of the population we wish to consider, we define the time elapsed (texp) from the start of exposure to the incinerator (ys) and the reference year (or year of calculation).

$$t_{\exp_{a\_i}} = \min\left\{\frac{a(M)_i - a(m)_i}{2}; y - ys\right\}$$

(1),

where:

a_i=i-th age class

a(M)i = max. age in i-th class

a(M)i = min. age in i-th class

y=reference year (or year of calculation) ys= year of start

Example: incinerator Modena (start in 1980), reference year : 2001, age class: 30-34 years

$$t_{\exp_{a\_30-34}} = \min\left\{\frac{34+30}{2};2001\text{-}1980\right\} = \min\{32;20\} = 20$$

Then

2. Cumulative exposure. For a given age class, cumulative exposure is given by the following formula:

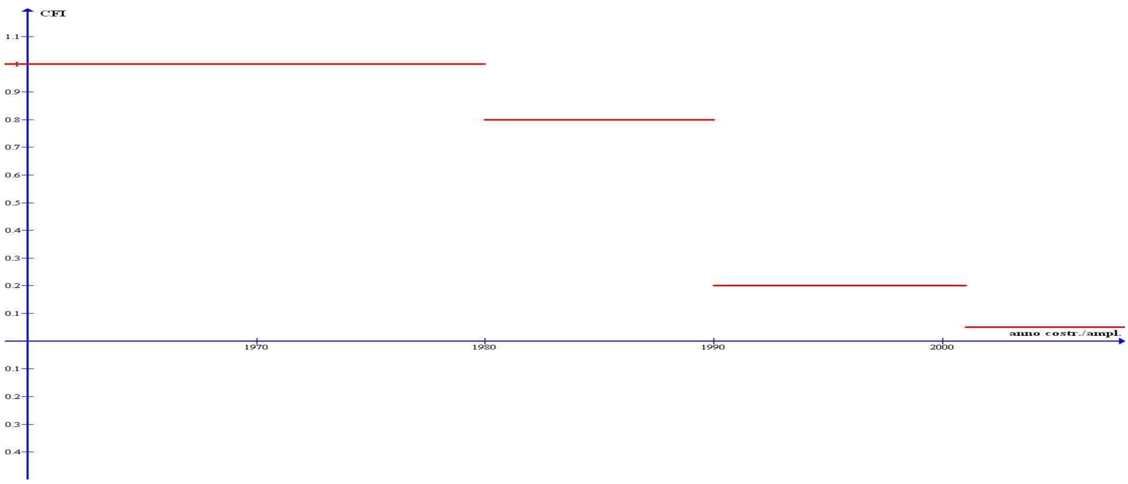
$$CE_{t_{\exp_{a\_i}}} = \sum_{t=1}^{t_{\exp_{a\_i}}} Ey(t) \qquad (2),$$

where Ey is the exposure factor for a given year according to the rule:

:

$$Ey(t) = \begin{cases} 1 & , \ t < 1980 \\ 0.8 & ,1980 \le t < 1990 \\ 0.2 & ,1990 \le t < 2001 \\ 0.05 & ,t \ge 2001 \end{cases} \qquad (3)$$

And shown in the graph below.



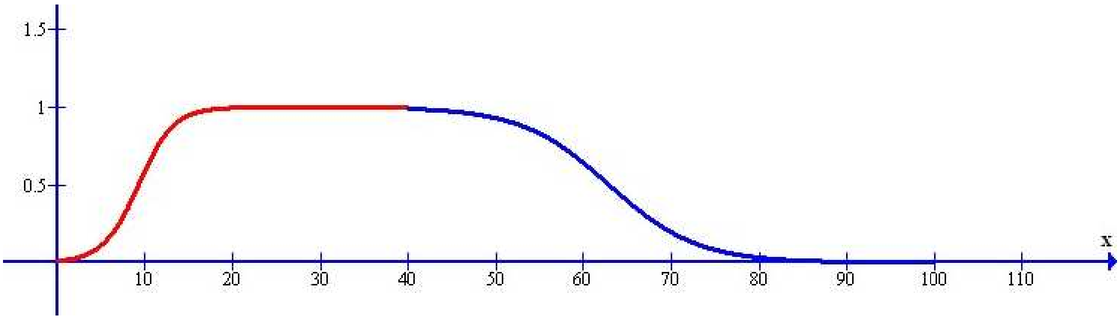
3. Latency since first exposure. We define then latency since start of exposure (Ls) for a given age class (a_i) as a function of the time variable indicated above:

$$Ls = f(t_{\exp_{a\_i}}) = \begin{cases} \dfrac{1}{1+b*e^{-ct_{\exp_{a\_i}}}} & , \quad t_{\exp_{a\_i}} \leq 40 \\ 1-\dfrac{1}{1+b*e^{-c(t_{\exp_{a\_i}}-40)}} & , \quad t_{\exp_{a\_i}} > 40 \end{cases} \quad (4),$$

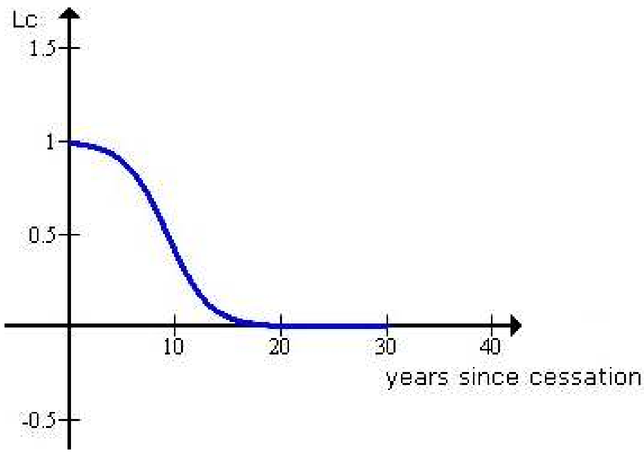
where:

Ls= latency since first exposure

b and c= coefficients for a sigmoid curve that reaches the plateau (one) 20 years since first exposure, remains stable until 40 years, and then starts to decline reaching 0 after 80 years as indicated in the graph below.



4.Latency since cessation of exposure. To allow for the possible effect of cessation of exposure, we assume a factor for latency since cessation of exposure (Lc) that follows a sigmoid with a decrease of the risk starting after the closure and reaching a plateau after 20 years as indicated in the graph below.



This factor follows the function below:

$$Lc = f(t_c) = 1-\frac{1}{1+b*e^{-c(t_c)}}$$

(5),

Where tc is time since cessation of exposure

For each age class and at a given time (year), the three factors indicated above (CE, Ls and Lc) act in a multiplicative way to modify the Reference Excess Risk (from Elliott et al. 1996).

Thus, for a given age class (a_i):

$$ER_{a\_i} = RER * (CE_{a\_i} / 20) * Ls * Lc \quad (6),$$

Where

ERa_i = the estimated excess risk of cancer incidence

RER =the reference excess risk as estimate from Elliott et al (1996) (3.5% increase for exposure of 20 years to incinerators operating before 1980).

CEa_i = cumulative exposure

Ls =latency since start of exposure

Lc =latency since cessation of exposure r

Finally, for a given age class (a_i):

$$AC_{a\_i} = ER_{a\_i} * Rate_{un\exp} * Pop_{\exp} \quad (7),$$

where

ACa_i =attributable cancer incidence

ER a_i =excess risk of cancer incidence

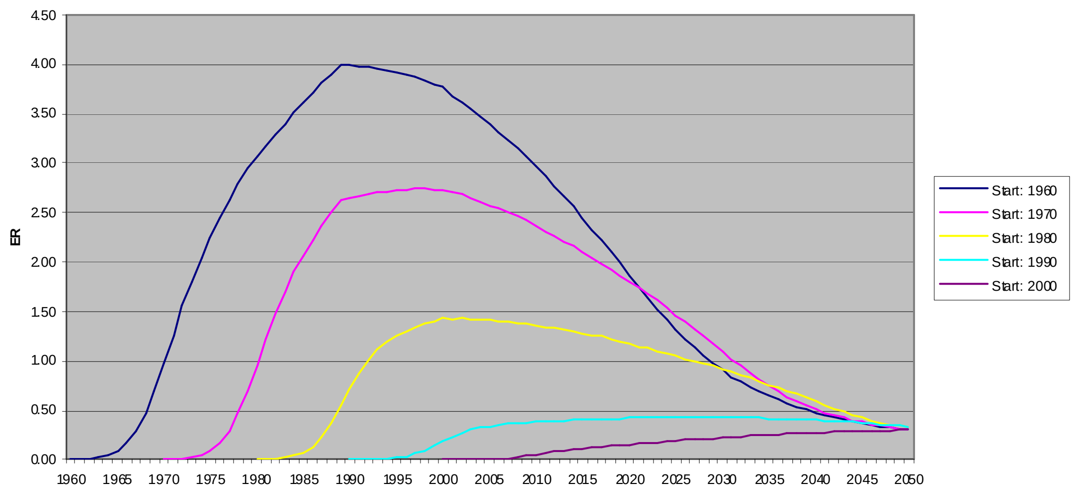
Rateunex =background incidence rate in the general population

Popexp =number of exposed people

Results

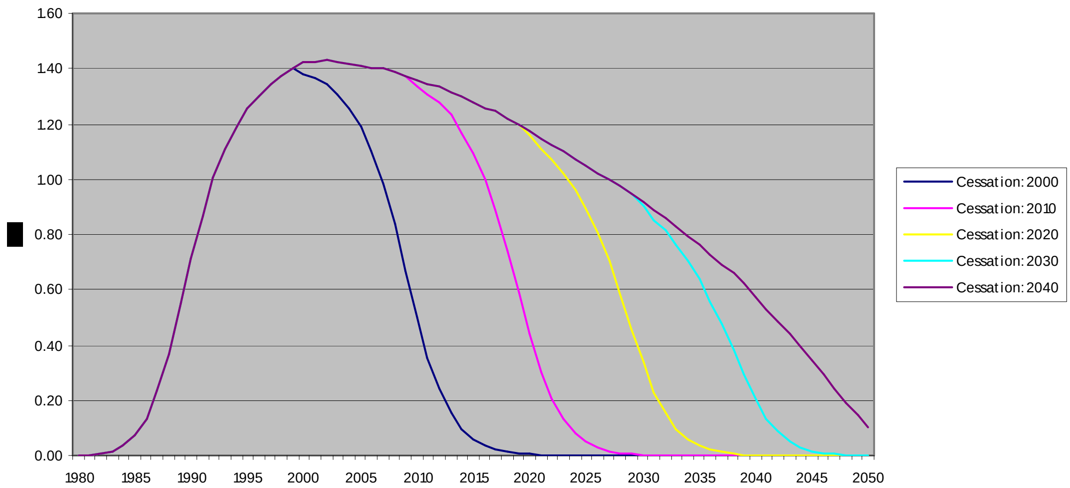
The figure below shows the results of the application of the model from 1960 to 2050. For each year, the excess risk (ER) (age weighted) of cancer is calculated with reference to a theoretical Italian population (age distribution) living close to an incinerator as function of year of starting operation.

Years of construction: 1960-2000



The next figure illustrate the estimated excess risk for a population living close to a plant operating since 1980 as function of the year of closing. The excess risks are reported up to 2050.

Start: 1980



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Annex 5. Glossary (from Environs, 2004 and Wikipedia).

Actinomycetes - a specific group of bacteria that are capable of forming very small spores.

Acute – referring to exposures and effects occurring on a relatively short timescale (e.g. hours or days).

Aeration - the process by which oxygen-rich air is supplied to compost to replace air depleted of oxygen.

Aerobic - an organism or process that requires oxygen.

Aerosol - a suspension in a gaseous medium of solid particles, liquid particles or

solid and liquid particles having a negligible falling velocity.

Anaerobic digestion - a series of processes in which microorganisms break down biodegradable material in the absence of oxygen, used for industrial or domestic purposes to manage waste and/or to release energy.

Allergic alveolitis - condition where the lungs are allergic to fungus and other allergens which cause inflammation of the alveolar region of the deep lung.

Asthma - narrowing of the bronchial tubes, where the muscles go into spasm and the patient has difficulty breathing.

Atopy - hereditary allergic reaction which includes diseases such as hay fever, asthma etc. where there is a clear family history of these conditions.

Bacteria - a group of micro-organisms with a primitive cellular structure, in which the genetic material is not retained within an internal membrane (nucleus).

Bioaerosol - micro-organisms suspended in the air.

Cardiovascular - of the heart and blood circulation system.

Cardiovascular disease - any disease which affects the heart or circulatory system.

Chronic - referring to exposures and effects occurring on a relatively long timescale, typically years.

Chronic pulmonary effects - Long-term disruption to the lung's ability to supply oxygenated blood to the heart.

Clinical health effect - condition causing evident symptoms.

Colorectal cancer - cancer of the colon or rectum.

Composting - a combination of decomposed plants and animal materials and other organic materials that are being decomposed largely through aerobic decomposition into a rich black soil.

Congenital anomaly - birth defect, a malformation that exists in a person's body from birth.

Congenital malformation - an abnormal development of a body structure which is present at birth.

Dioxin - (abbreviation for chlorinated dibenzo-para-dioxin) - a general term that describes a group of chemicals formed by the burning of substances containing chlorine and carbon.

Eczema - non-contagious inflammation of the skin.

Endotoxin - certain (toxic) substances found within bacterial cells and which are released only following damage to cells.

Epispadias - congenital defect where the urethra opens on the top of the penis and not on the end.

Exomphalos - a hernia (or rupture) present at birth which bulges at the navel.

Exposure-response coefficient - a factor (coefficient) representing the relationship between the amount of a toxic substance and a specific adverse effect, or the incidence of an adverse effect.

Fungi - a group of micro-organisms with a more complicated cellular structure than bacteria, in which the hereditary genetic material is retained within an internal membrane, forming a nucleus.

Furan - (abbreviation for chlorinated dibenzofuran) – a member of a group of substances formed under the same conditions as dioxins.

Gasification - reaction of waste materials or residues with air and steam in the "water-gas" reaction to form hydrogen and carbon monoxide.

Gastroschisis - a fissure or split in the abdominal wall, present at birth.

Glucans - polysaccharides composed of D-glucose in either straight or branched chains with glycosidic linkages.

Haemangiosarcoma - form of malignant tumour in a blood vessel.

Hazard – the potential of an activity, object or exposure to cause harm.

Hepatobiliary cancers - a specific cancer of the liver.

Hypospadias - congenital defect of the wall of the male urethra or the vagina, so that the opening occurs on the under side of the penis or in the vagina.

Incineration - a waste treatment technology that involves the combustion of organic materials and/or substances.Incineration and other high temperature waste treatment systems are described as "thermal treatment". Incineration of waste materials converts the waste into incinerator bottom ash, flue gases, particulates, and heat, which can in turn be used to generate electric power. The flue gases are cleaned of pollutants before they are dispersed in the atmosphere. Incineration with energy recovery is one of several waste-to-energy (WtE) technologies such as gasification, Plasma arc gasification, pyrolysis and anaerobic digestion. Incineration may also be implemented without energy and materials recovery

Landfill -a site for the disposal of waste materials by burial and is the oldest form of waste treatment.

Leukaemia – any of several malignant diseases in which an abnormal number of leucocytes (white blood cells) form in the blood.

M**echanical biological treatment** -a form of waste processing facility that combines a sorting facility with a form of biological treatment such as composting or anaerobic digestion.

Municipal solid waste (MSW) - solid waste collected by, or on behalf of local authorities.

Mycotoxins -toxic substances produced by fungi.

Neural tube - tube lined with ectodermal cells running the length of an embryo, which develops into the brain and spinal cord.

Neural tube defects - congenital defect which occurs when the edges of the neural tube do not close up properly (e.g. spina bifida).

Non-Hodgkin's lymphomas - tumours arising from lymphoid tissue that are not a result of Hodgkin's disease.

PM_{10} - mass concentration of particulate matter collected by a sampler with a 50% cut-point at an aerodynamic particle diameter of 10 µm; mostly particles with aerodynamic diameter of 10 µm or less.

$PM_{2.5}$ - mass concentration of particulate matter collected by a sampler with a 50% cut-point at an aerodynamic particle diameter of 2.5 µm, mostly particles with aerodynamic diameter of 2.5 µm or less.

Polychlorinated biphenyls (PCB) - a chloro–biphenyl organic pollutant produced in various industries.

Polycyclic aromatic hydrocarbons (PAHs) - hydrocarbon compounds with multiple fused benzene rings. PAHs are typical components of asphalts, fuels, oils, and greases.

Pyrolysis - heating of materials such as municipal solid waste in the absence of oxygen.

Risk – the likelihood that a hazard will actually cause harm.

Risk assessment – an evaluation, often quantitative in nature, of the level of risk associated with an activity, object or exposure.

Sarcoma - cancer arising in bone, connective tissue or muscle.

Spirometry - measurement of the vital capacity of the lungs and other related lung functional parameters..

Tracheo-bronchitis - inflammation of both the trachea and the bronchi.

Volatile organic compounds (VOCs) - a group of organic compounds that volatilise easily at ambient temperatures. Some VOCs are linked with environmental effects such as photochemical smog and ozone depletion, and some are toxic and/or carcinogenic.