Comparison of locations for a MSW incineration plant

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Abstract

The ExternE project is a research program of the European Commission devoted to the assessment of the external costs associated to airborne pollution. The ExternE methodology individuates the emission rates, calculates the year mean concentrations of the pollutants at the ground level on the basis of atmospheric dispersion models (e.g. AERMOD) and individuates the subjects exposed to the pollutants in the considered area (the number, the distribution and the age classes of the hit populations, types and distribution of crops). After that, proper exposure-response functions are applied in order to determine the impacts on the various receptors. In particular, impacts on human health, crops, building materials, forests and ecosystems can be calculated. Finally, the methodology can monetize the calculated physical impacts on the basis of particular econometric methods. The described methodology has been applied in order to find the best locality starting from three proposed sites for a municipal solid waste incinerator for the city of Turin, in North-Western Italy, by minimizing the total damage due to the emitted pollutants, taking into account the avoided emissions due to the realisation of a district heating system, to the increment of the electric energy production and to the reduction of the MSW landfilling in this way, the best localities correspond to the sites where a substantial increment of the district heating is possible. However, even if the district heating system wasn't increased by the incineration, the environmental balance would be largely positive.
Keywords: incinerator, AERMOD, concentration, district heating, damage, MSW, avoided emissions, environmental balance, advantage.

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1 Introduction

In the present paper we basically determine the damage on human health due to the pollutants emitted by the incineration of the solid waste deriving from the mechanical selection of the MSW produced by the metropolitan area of Turin (Piedmont), in North-Western Italy. There are three possible localizations for the incineration plant: Volpiano, 20 km far from Turin, Strada del Francese and Gerbido, respectively in the North-Western and South-Western part of Turin; each of these three choices has different possibilities of realising or increasing the district heating system, respectively for the area of Settimo Torinese, for Northern Turin and the centre of Turin.

2 The ExternE methodology

Externalities deriving from any production cycle represents the costs imposed on society as well as on the environment that are not accounted for by the producers and consumers of goods, that is which are not included in the market price; external costs constitute an heavy market failure which justifies strong intervention policies. The ExternE project [1] is the first and, at the moment, the most advanced and reliable attempt to use a consistent methodology to assess the external costs deriving from different fuel cycles since it comprises valuation techniques which integrate technical-scientific and economic analysis deriving both from existing international studies and from models of new application. The externalities evaluation techniques are divided into direct and indirect methods: as concerns the external costs due to pollution, the direct techniques characterize the facility to be analysed (technical features, emitted pollutants.), determine the pollutants pathway within a certain distance and measure the impacts on particular receptors. The direct method doesn't perform economic assessments but its technical analysis, based on atmospheric dispersion modelling and exposure-response toxicological functions, can evaluate, in statistical terms, the probability of certain negative events (for example, the probability of some respiratory pathology or the loss of crop quantities). On the other hand, the indirect methods are based on the perception of the damage that people think to receive as a consequence of the atmospheric pollution; consequently, these techniques observe the real behaviours of people who suffer from the impact and obtain from these behaviours a purely economic valuation. The underlying principle in monetary valuation is to obtain the willingness to pay (WTP) of an affected individual to avoid a negative impact, or the willingness to accept (WTA) payment as compensation if a negative impact takes place.

Obviously, the best approach for an exhaustive valuation of the externalities is the integration of both the techniques: the ExternE methodology applies the indirect analysis (the willingness to pay or to accept to avoid an estimated risk) downstream from the direct method, putting together all the best interdisciplinary capacities. Such methodology constitutes the so-called "impact pathway" approach; the analysis is based on 4 phases and proceeds in a sequential way from emissions towards the impact assessment and the respective monetization.

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Table 1: Exposure-response functions in ExternE for the receptor 'human health'.

	Health end point	Reference	receptor	f_{er} (cases/year/ person/µg/m³)	Unit cost (EURO2000/case)
FINE DUST (PM_{10}), NITRATES AND SULPHATES	Bronchodilator usage	Dusseldorp *et al.*, 1995	Asthmatic adults	1,63E-01	40
	Cough	Dusseldorp *et al.*, 1995	Asthmatic adults	1,68E-01	45
	Lower Respiratory Symptoms	Dusseldorp *et al.*, 1995	Asthmatic adults	6,06E-02	8
	Bronchodilator usage	Roemer *et al.*, 1993	Asthmatic children	7,75E-02	40
	Cough	Pope and Dockery, 1992	Asthmatic children	1,33E-01	45
	Lower Respiratory Symptoms	Roemer *et al.*, 1993	Asthmatic children	1,03E-01	8
	Congestive Heart Failure	Schwartz and Morris, 1995	Adults over 65	1,85E-05	3.260
	Chronic cough	Dockery *et al.*, 1989	Children	2,07E-03	240
	Restricted Activity Days	Ostro, 1987	Adults	2,50E-02	110
	Chronic Bronchitis	Abbey *et al.*, 1995	Adults	2,45E-05	169.330
	Respiratory Hospital Admissions	Dab *et al.*, 1996	Entire population	2,07E-06	4.320
	Cerebrovascular Hospital Admissions	Wordley *et al.*, 1997	Entire population	5,04E-06	16.730
	Chronic mortality (YOLL)	Pope *et al.*, 1995	Entire population	1,57E-04	96.500
SO_2	Respiratory Hospital Admissions	Ponce de Leon, 1996	Entire population	2,04E-06	4.320
	Acute mortality (YOLL)	Anderson & Toulomi, 1996	Entire population	6,16E-06	165.700
CO	Congestive Heart Failure	Schwartz and Morris, 1995	Adults over 65	5,64E-07	3.260
PAH	Lung cancer	U.S.EPA, 1990	Entire population	0,1/70*0,9	3.400.000
	Non fatal cancer	U.S.EPA, 1990	Entire population	0,1/70*0,1	485.943
PCDD/DF	Cancer	LAI	Entire population	1,4/70	3.400.000
Cadmium	Cancer	LAI	Entire population	1,2/100/70	3.400.000
Chromium	Cancer	WHO	Entire population	4/100/70	3.400.000
Arsenic	Cancer	LAI	Entire population	4/1000/70	3.400.000
Nickel	Cancer	U.S. EPA	Entire population	4/1000/70	3.400.000
Benzene	Cancer	U.S. EPA	Entire population	8/10^6/70	3.400.000

The first phase individuates the main technological features of facility, the pollutant concentrations (mg/Nm³), the emission rates (g/kWh) and the

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characteristics of the stacks (number, height and diameter). The second phase consists of the calculation of the year mean concentration of the pollutants at the ground level on the basis of atmospheric dispersion models. The third phase individuates the subjects exposed to the pollutants in the considered area and the correspondent characteristics (the number, the distribution and the age groups of the hit people, types and distribution of crops.). In the same phase, proper exposure-response functions are applied in order to determine the impacts on the receptors (these impacts are quantified as year additional cases of chronic bronchitis or asthma attacks for the human health, yield loss for the crops, etc.). As concerns the analysis of the effects on human health, which generally constitute the main contribute to the total monetary damage, the correspondent exposure-response functions are expressed as cases/(year*person*$\mu g/m^3$); this approach is clearly linear, without thresholds.

Finally, the fourth phase monetizes the calculated physical impacts on the basis of the WTP or WTA techniques described before. Table 1 reports the exposure-response functions and the corresponding monetization suggested by the ExternE project for the receptor 'human health'.

The ExternE methodology has been applied to several national implementation studies, analysing different electricity production cycles; the Italian report states that, on the regional scale (i.e. the entire continental Europe), the Italian power plants cause, on the average, a damage to the human health of 22,09 $mEURO_{2000}$/kWh. In the end, the ExternE project can also quantify the damages due to the emissions of greenhouse gases on the global scale. The most recent and reliable model (FUND 2.0) gives the following estimates: 2,4 EURO/t CO_2 and 44,9 EURO/t CH_4.

3 Data at disposal

3.1 Technical features and possible localization

As concerns the plant, the incinerator would be fed by 245.000 t/y of selected MSW (approximately 34 t/h, composed by 38,6% C, 5,1% H, 22,4% O, 1,0% N, 0,1% S, 0,8% Cl, 15,0% ashes and 17,1% H_2O, enthalpy of combustion = 3.595 kcal/kg). The thermal power of the plant is 142,2 MW. The emitted flow is approximately 258.138 Nm^3/h, with a humidity volume of 15% and an oxygen content near 9,4% (vol/vol for dry smoke). The flue gas temperature has been assumed 140 °C, the stack height is 80 m and the stack diameter is 3 m. The emission limits for the incineration can be referred to the EC regulations, in particular 76/2000/CE; on the other hand, the emission levels, taken from measurements on existing plants, can be often much smaller than the limits, as reported in Table 2.

Table 3 reports the different features relating to the electric energy generated by the incinerator, the distributed thermal energy and the avoided emissions from the displaced heating plants for the three sites. It is important to observe that the assumed scenarios would overlap the existing district heating systems which, at present, are supplied by cogeneration plants: as a consequence, the net displaced heating plants are fewer than those corresponding to the total distributed thermal energy whereas the electric energy generated by the cogeneration plants can be larger. We assume that the existing heating plants burn natural gas (77%), gas oil (20,6%) and oil (2,4%). The avoided emissions should be modelled over 6 months per year, 14 h/d; we supposed that the eliminated sources have a flue gas temperature of 180°C, a stack exit gas velocity of 2,5 m/s, a stack height of 20 m and a thermal power of approximately 2 MW each. On the other hand, the incinerator has been assumed to emit continuously over the entire year.

Table 2: Emission limits and levels for a MSW incinerator.

POLLUTANT	**EMISSION LIMITS** (mg/Nm^3, dry gas, O_2 @ 11%)	**EMISSION LEVELS** (mg/Nm^3, dry gas, O_2 @ 11%)	**YEARLY MASS FLUX (t/y)**
TSP	10	1	2,2
NO_2	200	60	134,4
SO_2	50	10	22,4
CO	50	25	55,9
Σ Heavy metals	0,5	0,1	0,2
PAH	0,01	0,002	4 E-3
PCDD/DF (ng/m^3)	0,1	0,05	1 E-7
Cd+Tl	0,05	0,02	4 E-2
T.O.C.	10	10	22,4
HCl	10	10	22,4
HF	1	1	2,2
Hg	0,05	0,05	0,1
Zn	5	5	11,2

Table 3: Three possible sites for the incinerator.

	VOLPIANO	STRADA DEL FRANCESE	GERBIDO
Electric energy (GWh/y)	232,6	213,5	205,7
Thermal energy (GWh/y)	103,5	364,7	475,5
Net displaced heating plants (GWh/y)	6,8	127	145,5
Avoided emission (t/y) referable to the increased district heating system	NO_2: 1,5 SO_2: 0,7 TSP: 0,1 CO: 0,9 CO_2: 1.400	NO_2: 27,6 SO_2: 10,4 TSP: 1,2 CO: 17,8 CO_2: 25.900	NO_2: 31,7 SO_2: 10,4 TSP: 1,2 CO: 20,4 CO_2: 29.600
Increment of electric energy generated by existing cogeneration plants (GWh/y)	18,8	49,2	75,8

3.2 Meteorological data and atmospheric modelling

We have at disposal a meteorological database for 1 year, from June 1st, 1999 to May 31st, 2000, calculated for the entire Province of Turin by means of the diagnostic model MINERVE and the meteorological pre-processor SURFPRO. In order to calculate, on the local scale, the year mean concentrations of the pollutants at the ground level referable to the incinerator or to the emissions from the displaced heating plants, we applied the AERMOD model by U.S. EPA [2],

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which was born to replace the Industrial Source Complex Model (3rd version), up to now used for the environmental planning, the risk assessment and the emission permits in the U.S.A.. AERMOD is a steady state plume model that was designed for the short-range simulations (distances from sources generally smaller than 50 km), both for simple and complex orography. The AERMOD model has been applied to domains measuring 40 km * 40 km round the plant (i.e. on the local scale), with a spatial resolution of 200 m, for one entire year (40401 points, 8784 hours for each point); in the present study, we adopted the regulatory default options of the model. The results of the atmospheric dispersion modelling on the local scale dealing with the three sites for the incinerator and the corresponding displaced heating (avoided emissions) are reported in details in the paper entitled "Results of atmospheric dispersion model for the localization of a MSW incinerator" (Brizio, Genon, Poggio [3]). Table 4 reports the yearly mean concentrations averaged over the entire domain and the maximum punctual yearly mean concentrations due to the incinerator for the most worrying urban pollutants, i.e. the total suspended powder (TSP) and the nitrogen oxides (NO_X); the maximum calculated hourly mean concentrations for the three proposed sites are 0,2 $\mu g/m^3$ for TSP and 12 $\mu g/m^3$ for NO_2.

Table 4: Calculated yearly mean concentrations at the ground level for the incinerator.

	VOLPIANO	STRADA DEL FRANCESE	GERBIDO
Maximum punctual yearly mean concentration	TSP: 0,0081 $\mu g/m^3$ NO_2: 0,486 $\mu g/m^3$	TSP: 0,0068 $\mu g/m^3$ NO_2: 0,408 $\mu g/m^3$	TSP: 0,0048 $\mu g/m^3$ NO_2: 0,288 $\mu g/m^3$
Yearly mean concentration averaged over the domain	TSP: 0,00047 $\mu g/m^3$ NO_2: 0,0282 $\mu g/m^3$	TSP: 0,00038 $\mu g/m^3$ NO_2: 0,0228 $\mu g/m^3$	TSP: 0,00040 $\mu g/m^3$ NO_2: 0,0240 $\mu g/m^3$

On the other hand, Table 5 points out the avoided concentrations from the displaced heating plants. As one can easily observe, in the case of Northern Turin and the centre of Turin, the displaced heating produces much larger concentrations at the ground level than the corresponding incinerator (even more than 10 times in the case of TSP), although the total annual emissions are smaller (a half for TSP, CO and SO_2, a quarter for NO_X); moreover, the maximum concentrations are placed round the sources. This effect can be explained by the physical and technical features of the corresponding sources, which are generally not far from the ground level and with low stack exit gas velocity.

Table 5: Calculated yearly mean concentrations at the ground level for the displaced heating plants.

	SETTIMO TORINESE	NORTHERN TURIN	CENTRE OF TURIN
Maximum punctual yearly mean concentration	TSP: 0,005 $\mu g/m^3$ NO_2: 0,081 $\mu g/m^3$	TSP: 0,058 $\mu g/m^3$ NO_2: 1,325 $\mu g/m^3$	TSP: 0,060 $\mu g/m^3$ NO_2: 1,575 $\mu g/m^3$
Yearly mean concentration averaged over the domain	TSP: 0,00012 $\mu g/m^3$ NO_2: 0,002 $\mu g/m^3$	TSP: 0,00129 $\mu g/m^3$ NO_2: 0,030 $\mu g/m^3$	TSP: 0,00171 $\mu g/m^3$ NO_2: 0,045 $\mu g/m^3$

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As concerns the regional scale (European-wide), the concentrations at the ground level have been calculated by means of the Lagrangian model Windrose Trajectory Model (WTM), developed by the Harwell Laboratories and included in the ECOSENSE model (Heck et al. [4]). The Windrose Trajectory Model considers the atmospheric chemical reactions; as a consequence, it can calculate the concentrations of the acid species formed in atmosphere (i.e. nitrates and sulphates).

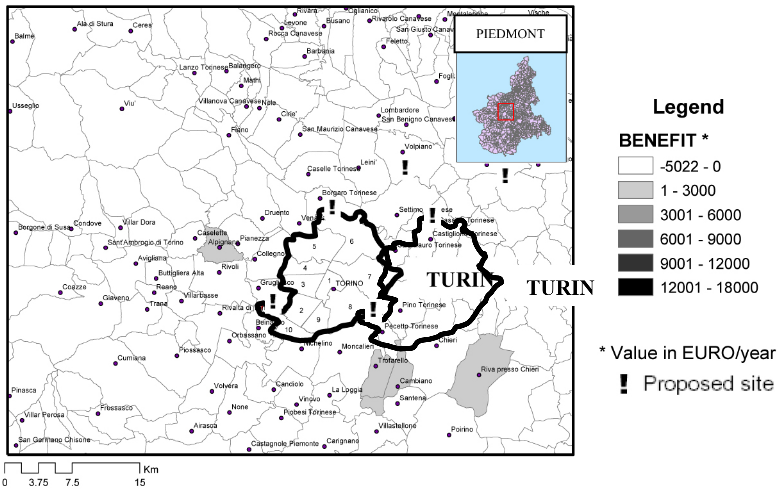

Figure 1: Local environmental balance for the site of Volpiano.

4 Application of the ExternE approach to the case study

On the basis of the performed atmospheric modelling, we can calculate the additional damages to the receptor ‘human health’ due to the incinerator and the avoided impacts referring to the displaced heating plants, both on the local and the regional scale. To do this, we have at disposal, for the local domains, the population data of the census 2001, interpolated with a resolution of 200 m. The damages referable to the incinerator on the local scale are 66.690, 115.501 and 113.976 EURO/year, respectively for Volpiano, Strada del Francese and Gerbido, whereas the damage on the regional scale is 1.329.968 EURO/year (it doesn’t depend on the precise site because of the considered distances); 70% of the calculated damages is due to emitted heavy metals (Cd, Cr, Ni and As), whose emission levels are for sure overestimated. On the other hand, the increment of the district heating system would cause the following avoided damages to the human health: on the local scale, 6.228, 168.487 and 165.113 EURO/year respectively for Settimo Torinese (connected with the site of Volpiano), Northern Turin (depending on Strada del Francese) and the centre of Turin (in relation to Gerbido); on the regional scale, 18.696 EURO/year for Settimo, 289.113 EURO/year for Northern Turin and 321.104 EURO/year for the centre of Turin. About 70% of the calculated avoided damages are referable

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this time to the emitted dust. As one can easily observe, when the development of the district heating is substantial (the cases of Strada del Francese and Gerbido), the additional damages of the incinerator are exceeded by the advantages due to the displaced heating, even on the local scale. This happens because of the low emission levels of modern incinerators; moreover, the pollutants deriving from the incinerator are emitted by high stacks (80 m) and the plume has large momentum (15 m/s), which causes considerable plume rises and the interaction of the plume with atmospheric layers characterized by higher wind speed. As a consequence, the pollutants undergo a better dilution than in the case of the heating plants and produce smaller damages. In order to have a more detailed information, Fig. 1, Fig. 2 and Fig. 3 report the environmental balance of the damages on the local scale (expressed in EURO/year, positive in the case avoided damages exceed the additional ones), disaggregated according to the town boundaries; as it is clear, the best local balances are Strada del Francese and Gerbido where many Communes or town district have environmental benefits deriving from the increase of the district heating.

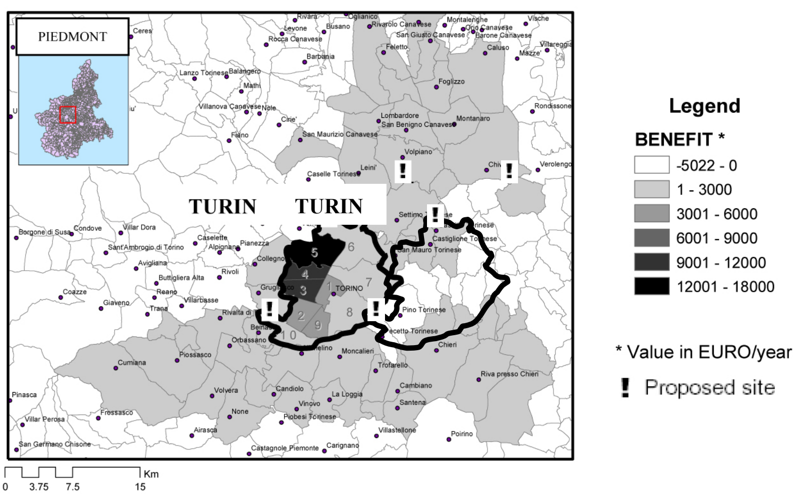

Figure 2: Local environmental balance for the site of Strada del Francese.

Anyway, the disaggregated advantage distribution is significantly different for the two cases: for Strada del Francese, the whole city of Turin has a positive balance, whereas, in the case of Gerbido, the Eastern part of Turin has a light disadvantage and the western part has large benefits. In the same way, for Strada del Francese, a larger number of towns would reach a positive balance, yet the benefits would be smaller if compared with some cases of the Gerbido configuration. This effect is due to the localization of the incinerator and to the anemology in the two cases: for the centre of Turin, the wind directions are less homogeneous (i.e. 2 main directions) than in Northern Turin and the site of Gerbido is quite far from the centre. As a consequence, in the case of Gerbido,

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the avoided damages are less distributed (i.e. they are concentrated in smaller areas), giving larger environmental benefits, also outside Turin.

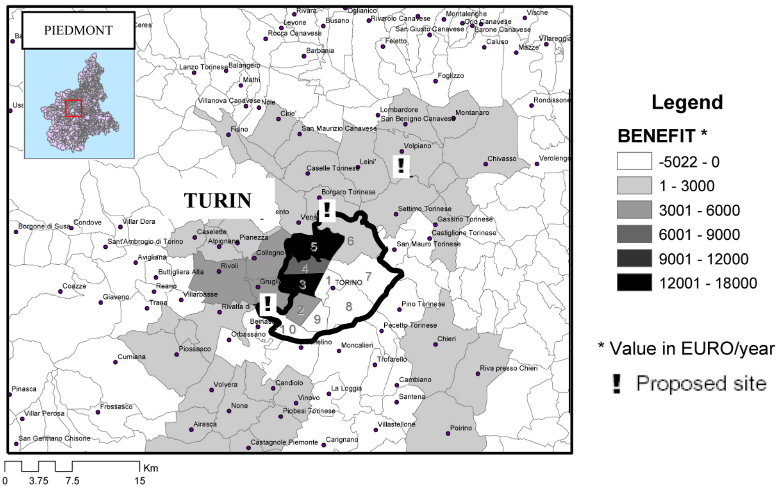

Figure 3: Local environmental balance for the site of Gerbido.

As concerns the electric energy produced by the incinerator, we can think that it can replace the same amount of energy generated by whatever Italian power plant, which causes a damage to the human health of 22,09 $mEURO_{2000}$/kWh; this way, the avoided damages are 5.554.493 EURO/year for Volpiano (232,6 GWh/year from the incinerator + 18,8 GWh/year as increment of the existing cogeneration plants), 5.804.158 EURO/year for Strada del Francese (213,5 + 49,2 GWh/year) and 6.219.529 EURO/year for Gerbido (205,7 + 75,8 GWh/year). As for the global damages due to the emitted or avoided greenhouse gases, the incinerator would produce 344.960 t/year of CO_2 ($C_{3,2}H_{5,1}O_{1,4}N_{0,07}$ + 3,775 O_2 = 3,2 CO_2 + 2,55 H_2O) whereas the avoided CO_2 emissions from the displaced heating are reported in Table 3. Moreover, it is important to observe that the mean CO_2 emission factor from the Italian power plants is 680 g/kWh: on this basis, the incinerator would avoid the production of 170.952 t/year of CO_2 if placed in Volpiano, 178.636 t/year in the case of Strada del Francese and 191.420 t/year for Gerbido. Furthermore, the choice of the incineration of the MSW would eliminate the emissions of CO_2 and CH_4 from the corresponding landfill: ($C_{3,2}H_{5,1}O_{1,4}N_{0,07}$ + 1,2775 H_2O = 1,86125 CH_4 + 1,33875 CO_2 + 0,07 NH_3). If we assume that 55% of biogas is collected and burnt, the avoided emissions of CH_4 is 32.832 t/year, 254.671 t/year for CO_2. The damages due to the greenhouse gases can be determined by the FUND 2.0 model (see chapter 2).

Table 6 reports the environmental balance which takes into account all the voices of damage (avoided and additional) described before. The balance, on the whole, is largely positive for the three sites, i.e. the sum of the avoided damages exceeds the additional ones; in particular, the balance is always positive on the regional scale and the global scale whereas, on the local scale, it is positive for Strada del Francese and Gerbido but it is slightly negative for Volpiano, because of the small increment of the district heating. Anyway, the best localizations (maximum environmental benefit) are Strada del Francese and Gerbido: the sites are substantially equivalent on the local scale, while, on the regional scale and the global scale, Gerbido is preferable because of the larger production of electric energy. In the case the incinerator didn't generate thermal energy in order to integrate the existing district heating, the avoided damages due to the displaced heating would be obviously zero whereas the avoided damages on the regional scale and the global scale due to the production of electric energy would be respectively 5.307.037 EURO/year and 392.006 EURO/year (for the "exclusively electrical" set-up, the produced electric energy is 240,2 GWh/year). In this case, the preferable site is Volpiano because of the smaller damages referable to the incinerator on the local scale.

Table 6: Environmental balance for the three localizations.

					VOLPIANO	STRADA DEL FRANCESE	GERBIDO
		SCALE	DIMENSIONS	PARAMETERS	EURO /year	EURO /year	EURO /year
ADDITIONAL DAMAGES	incinerator	Local	40 km * 40 km	TSP, CO, SO_2, μ–pollutants	66.690	115.501	113.976
	incinerator	Regional	European-wide	TSP, CO, SO_2, NOx, μ–pollutants, nitrates and sulphates	1.329.968	1.329.968	1.329.968
	incinerator	Global	planetary	CO_2	827.904	827.904	827.904
				TOTAL	**2.224.561**	**2.273.373**	**2.271.847**
AVOIDED DAMAGES	displaced heating	Local	40 km * 40 km	TSP, CO, SO_2	6.228	168.487	165.113
	displaced heating	Regional	European-wide	TSP, CO, SO_2, NOx, nitrates and sulphates	18.696	289.113	321.104
	displaced heating	Global	planetary	CO_2, CH_4	3.360	62.160	71.040
	electric energy production	Regional	European-wide	TSP, CO, SO_2, NOx, nitrates and sulphates	5.554.493	5.804.158	6.219.529
	electric energy production	Global	planetary	CO_2	410.285	428.726	459.408
	landfill	Global	planetary	CO_2, CH_4	2.085.367	2.085.367	2.085.367
				TOTAL	**8.078.429**	**8.838.012**	**9.321.561**
			ENVIRONMENTAL BALANCE		**5.853.867**	**6.564.639**	**7.049.714**

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5 Conclusions

The ExternE methodology enables to localize the MSW incinerator by minimizing the monetary damages of the corresponding emissions and by maximizing the environmental advantages. According to the three proposed sites, the damage to the human health due to the incinerator on the local scale goes from 67.000 to 116.000 EURO/year. The environmental balance can comprehend also other voices, such as the avoided damages relating to the displaced heating, the avoided damages on the regional scale due to the electricity produced by the incinerator and the global impact relating to the emissions (avoided and additional) of greenhouse gases from the incinerator, the landfill, the power plants and the heating plants. On these bases, the total environmental balance came out strongly positive for the three sites, in particular on the regional and the global scale; the balance can be positive even on the local scale in the case the district heating is significantly increased by the incinerator.

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