Optimization of C&D waste management by the application of Life Cycle Assessment (LCA) methodology: the case of the Municipality of Rome, Italy

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Abstract

In recent years, in Italy, a large quantity of construction and demolition (C&D) waste has been generated: in the year 2004 a production of about 46,0 Mt of C&D waste has been estimated. After mechanical treatment, this waste can be recovered and recycled as secondary raw material, determining economic and environmental benefits, by reducing landfill, transportation and primary resources consumption. To date, the recycling rate of C&D waste in Italy is only 10%, due to the amount of recycled product. This study is aimed at carrying out an analysis of C&D waste flow, in the Municipality of Rome, Italy, considering both the amount properly disposed or recycled, and the amount illegally dumped on the territory or in the containers for municipal solid waste. Furthermore, application of the Life Cycle Assessment (LCA) methodology has been applied in order to optimize C&D waste recycling, considering the environmental impact connected to different C&D waste management schemes. Data obtained from the LCA methodology allowed one to quantify the environmental performance, to estimate the costs of each scheme considered, and finally to evaluate the best C&D waste management.

Keywords: C&D waste, waste management, recycling, LCA.

1 Introduction

In many countries, construction and demolition (C&D) waste generation has been increasing over the past decade, due to social and economic factors, such as population increase and rapid growth of towns and cities.

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Despite recycling becoming a consolidated issue, landfilling and, even worse, illegal dumping are still widespread practice.

The European Union, in the framework of the Sixth Environment Action Programme [1], in accordance with the EU Waste Strategy, has established that it is necessary to take action to improve the efficiency in C&D waste management, since the annual quantity generated exceeds 450 million tonnes, while the percentage of material recovery is only 25% [2].

Several European countries have implemented a national policy to encourage preventing production and promoting reuse, recycling and recovery of C&D waste in accordance to EU waste hierarchy [3–8].

2 The C&D waste

C&D waste is composed of different typologies of materials, in variable percentage, depending on waste source, construction technologies, building characteristics, local raw materials. An average composition in weight of C&D waste in Italy is reported in Table 1 [9].

Table 1: Average composition of C&D waste in Italy.

Waste category	%wt
Concrete	30,0
not reinforced concrete	*10,0*
reinforced concrete	*20,0*
bricks (tile, perforated brick, etc.)	50,0
asphalt	5,0
excavated ground	6,0-10,0
paper and cardboard	0,6-4,0
metals	3,0
others	1,0-1,4

The C&D waste production derives mainly from building renovation by private citizens, which generates small amounts of waste to be recovered or disposed of. Sometimes, the distance from the construction site to the recycling or disposal plants favours illegal waste disposal.

In the Northern Europe, the highest levels of recovery and/or recycling of C&D waste are found (Table 2), firstly due either to a shortage in natural resources, either to a well-established environmental culture. Secondly, the imposition of political measures, such as taxation and restrictive rules on waste disposal, aimed at reducing landfilling of recoverable materials, has led to the increase in reusing secondary raw materials from C&D waste and, on the other hand, to lower the exploitation of primary raw materials from quarrying.

In comparison with Northern Europe, in Italy, the recovery of C&D waste is strongly limited by the abundance of affordable natural resources and by a diffuse and unchecked illegality in C&D waste disposal.

Table 2: Production, recovered/recycled and landfilled C&D waste in Europe [10].

	production	recovery/recycling		landfilling	
Country	Mt/yr	Mt/yr	%	Mt/yr	%
Germany	59,00	10,03	17	48,97	83
UK	30,00	13,50	45	16,50	55
France	23,60	3,54	15	20,06	85
Italy	20,00	1,80	9	18,20	91
Spain	12,8	1,13	8,8	11,67	91,2
Netherlands	11,17	10,17	91	1	9
Belgium	6,75	6,19	92	0,56	8
Austria	4,70	1,93	41	2,77	59
Greece	1,80	0,07	4	1,73	96
Portugal	3,20	0,13	4	3,07	96
Denmark	2,64	2,22	84	0,42	16
Sweden	1,69	0,64	38	1,05	62
Finland	1,35	0,93	69	0,42	31
Ireland	0,57	0,01	1	0,56	99
Luxembourg	0,30	0,05	17	0,25	83
Total UE	*179,57*	*52,34*	*29*	*127,23*	*71*

To promote the recovery of C&D waste against landfilling (all the more so against illegal landfilling), actions should be taken to relieve the pressures on disposal spaces as well as respecting the hierarchy of waste management.

3 The case study

The aim of this study is to optimise the management of C&D waste flow in the municipality of Rome, Italy, in order to facilitate recovery/recycling and to minimise the environmental impacts due to C&D waste transportation.

In particular, a different scheme of transportation from construction sites inside the city to recycling/disposal sites has been analysed, in order to improve materials recovery and to reduce heavy traffic in the metropolitan area.

The amount of C&D waste production is proportional to the construction site size. The widest ones, which produce large amounts of waste, can use trucks with great carrying capacity and optimise the transport. On the other hand, the smallest construction sites, which produce lower amounts of waste, utilise vehicles with a small truckload. As a consequence, the impact on metropolitan traffic is considerable, because of the numerous heavy transports inside the city.

The exact determination of C&D waste production in the city of Rome is quite difficult for the following reasons:

- the latest official data on waste disposal are related to the year 2006 [11], based on the so-called MUD, a formal declaration on waste production carried out by waste producers in Italy;

- after a national legislative decree (D.Lgs. 152/2006), the producers of non-hazardous waste are non obligated to the formal declaration;
- the most part of C&D waste derives from the activity of small property developers, often operating without legal permission, increasing outlaw waste disposal.

A general assessment of C&D waste production in Italy has been made by ANPAR (Associazione Nazionale Produttori di Aggregati Riciclati, a national association among producers of recycled aggregate), differentiated in Northern, Central and Southern Italy, analysing the amount of C&D waste conferred to recycling plants. The productivity rate of C&D waste in Central Italy has been set to 510 kg/yr per inhabitants [12].

The C&D waste production (Table 3) in the city of Rome can be estimated considering the resident population (census at 31/12/2008).

Table 3: Estimated total C&D waste production in the city of Rome.

productivity rate of C&D waste *t/inhabitants* year*	inhabitants *at 31/12/2008*	C&D waste production *t*
0,51	2.811.609	1.433.921

The main part of such C&D waste production derives from so-called micro-demolition, due to residential and non-residential renovation, which accounts altogether for 92% of the total C&D waste, (Bressi [12], refers 53% residential, 39% non-residential) (Table 4). The production from micro-demolition is responsible for heavy transport in the city area and for illegal dumping.

Table 4: Estimated C&D waste production from micro-demolition in the city of Rome.

Total	From micro-demolitions	
t	*%*	*t*
1.433.921	92	1.319.207

Such production can be divided into the 20 administrative districts, defined within the metropolitan area, in relation to the inhabitants of each district (Table 5).

3.1 Assessment of the current scheme of C&D waste transportation

The current scheme of C&D waste transportation from micro-demolitions in the Municipality of Rome is represented in Figure 1. The C&D waste produced by micro-demolitions has to be transferred from the city area to the recycling or disposal plants, generally located out of the metropolitan area (Figure 2).

The transport is usually made with 3,5-t vehicles (maximum payload: 2 t) because of the small amount of material to be moved. It is can be divided into three parts:

Table 5: Distribution of C&D waste production from micro-demolition in each city district of the city of Rome.

City district	inhabitants	C&D waste produced *t*
1	126.703	59.449
2	122.785	57.611
3	53.361	25.037
4	199.771	93.733
5	178.587	83.793
6	123.373	57.887
7	121.993	57.239
8	224.672	105.416
9	126.630	59.415
10	181.929	85.361
11	135.852	63.742
12	171.650	80.538
13	216.515	101.589
15	150.876	70.791
16	142.011	66.632
17	70.459	33.059
18	135.100	63.389
19	181.645	85.228
20	147.697	69.299
total	*2.811.609*	*1.319.207*

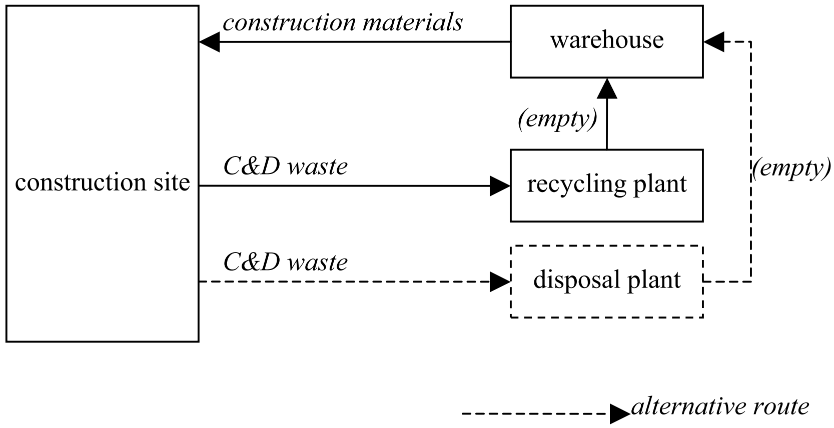

Figure 1: Flowchart of the current scheme of C&D waste transportation in the Municipality of Rome.

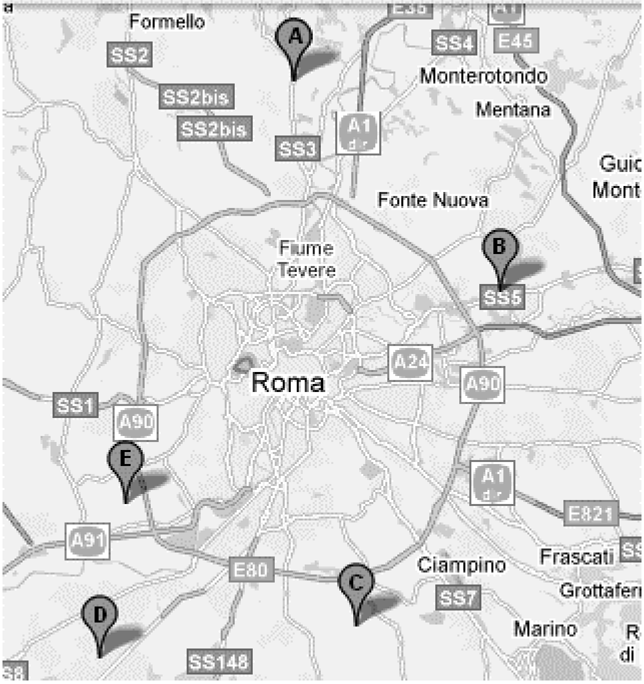

Figure 2: Location of recycling and disposal plants in the Municipality of Rome.

1) firstly, the vehicle moves from the construction site to the recycling or disposal plant, where C&D waste is unloaded;
2) then, the vehicle usually proceeds to the warehouse in order to freight construction materials;
3) finally, the vehicle returns to the construction site.

For each city district, the distance between the barycentre (where construction sites are supposed to be) and the nearest recycling (or disposal) plant has been calculated (Table 6), while an average distance of 4 km has been considered between recycling (or disposal) plants and warehouses, which are quite disseminated in and out of the city area.

Under these hypotheses, the total kilometres per year currently covered for C&D waste transportation can be calculated, as reported in Table 7.

3.2 Assessment of an alternative scheme of C&D waste transportation

An alternative scheme of C&D waste transportation from micro-demolitions in the Municipality of Rome is proposed, as represented in Figure 3. In this case, the C&D waste produced by micro-demolitions has to be transferred by 3,5-t vehicles from the city area to the nearest warehouse, quite disseminated within be divided into two stocks: recoverable and non-recoverable. Then, when an

Table 6: Distances (city district barycentre - nearest recycling/disposal plant).

City district	Recycling or disposal plant	distance (km)
I	E	16,7
II	A	20,1
III	B	16,0
IV	A	19,7
V	B	10,2
VI	B	12,0
VII	B	11,2
VIII	B	10,7
IX	C	17,0
X	C	15,3
XI	C	13,2
XII	C	10,1
XIII	D	10,8
XV	E	10,6
XVI	E	13,1
XVII	E	15,0
XVIII	E	13,1
XIX	A	18,4
XX	A	20,2

adequate amount of C&D waste is cumulated, the transportation to the recycling plant (or to the disposal plant of non-recoverable waste) can be made by 44-t vehicles. In this way, the longest distance to the recycling (or disposal) plant is covered by large full-load vehicles.

Nineteen operating warehouses have been chosen, with suitable characteristics to serve as C&D waste stock, conveniently distributed within the city area. In Table 8 the average distances between the barycentre of each city district (where construction sites are supposed to be) and the warehouse are reported.

The C&D waste is collected in containers, 5,8 x 2,5 x 1,2 m in size, net volume equal to 10 m^3 (gross volume equal to 17 m^3). Considering a specific weight of 1,7 t/m^3 and a filling rate of 90%, the total net weight of the container is about 15 t (gross weight equal to16 t). Taking into consideration the weight limit of 44 t for truck circulation, each truck transports 2 containers, that is 30 t net C&D waste.

Under these hypotheses, the total kilometres per year currently covered for C&D waste transportation can be calculated, as reported in Tables 9 and 10.

Table 7: Kilometres per year currently covered for C&D waste transportation.

City district	C&D waste *t/yr*	distance *km*	route length *km*	# journeys *per year*	total km *km/yr*
I	59.449	16,7	37,4	29.725	1.111.697
II	57.611	20,1	44,2	28.805	1.273.197
III	25.037	16,0	36,0	12.518	450.666
IV	93.733	19,7	43,4	46.866	1.987.130
V	83.793	10,2	24,4	41.897	980.378
VI	57.887	12,0	28,0	28.943	839.356
VII	57.239	11,2	26,4	28.620	755.556
VIII	105.416	10,7	25,4	52.708	1.286.076
IX	59.415	17,0	38,0	29.707	1.099.174
X	85.361	15,3	34,6	42.681	1.476.747
XI	63.742	13,2	30,4	31.871	1.096.358
XII	80.538	10,1	24,2	40.269	1.014.781
XIII	101.589	10,8	25,6	50.794	1.401.926
XV	70.791	10,6	25,2	35.396	998.153
XVI	66.632	13,1	30,2	33.316	1.172.715
XVII	33.059	15,0	34,0	16.530	595.069
XVIII	63.389	13,1	30,2	31.694	957.173
XIX	85.228	18,4	40,8	42.614	1.738.648
XX	69.299	20,2	44,4	34.650	1.538.447
total	*1.319.207*			*659.603*	*21.773.248*

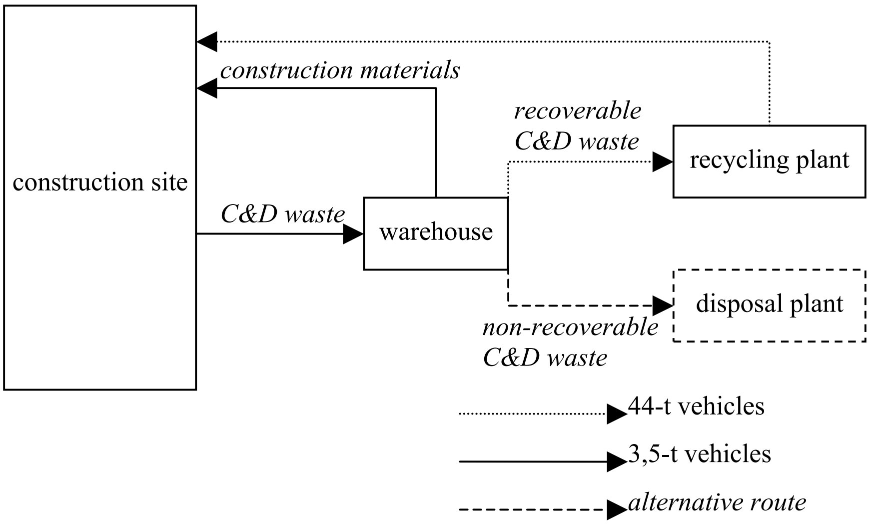

Figure 3: Flowchart of the alternative scheme of C&D waste transportation in the Municipality of Rome.

Table 8: Distances (city district barycentre - nearest warehouse).

City district	distance (km)
I	4
II	4
III	4
IV	3
V	3
VI	5
VII	4
VIII	3
IX	3
X	4
XI	8
XII	5
XIII	6
XV	7
XVI	9
XVII	6
XVIII	4
XIX	4
X	4

Table 9: Kilometres per year covered for C&D waste transportation by 3,5-t vehicles in the alternative scheme.

City district	C&D waste *t/yr*	# journeys *per year*	route length *km*	total km *km/yr*
I	59.449	29.725	8	237.800
II	57.611	28.805	8	230.440
III	25.037	12.518	8	100.144
IV	93.733	46.866	6	281.196
V	83.793	41.897	6	251.382
VI	57.887	28.943	10	289.430
VII	57.239	28.620	8	228.960
VIII	105.416	52.708	6	316.248
IX	59.415	29.707	6	178.242
X	85.361	42.681	8	341.448
XI	63.742	31.871	16	509.936
XII	80.538	40.269	10	402.690
XIII	101.589	50.794	12	609.528
XV	70.791	35.396	14	495.544
XVI	66.632	33.316	18	599.688
XVII	33.059	16.530	12	198.360
XVIII	63.389	31.694	8	253.552
XIX	85.228	42.614	8	340.912
XX	69.299	34.650	8	277.200
total	*1.319.207*	*659.603*		*6.142.700*

Table 10: Kilometres per year covered for C&D waste transportation by 44-t vehicles in the alternative scheme.

City district	C&D waste *t/yr*	# journeys *per year*	route length *km*	total km *km/yr*
I	59.449	1.982	16,7	33.099
II	57.611	1.920	20,1	38.592
III	25.037	835	16,0	13.360
IV	93.733	3.124	19,7	61.543
V	83.793	2.793	10,2	28.489
VI	57.887	1.930	12,0	23.160
VII	57.239	1.908	11,2	21.370
VIII	105.416	3.514	10,7	37.600
IX	59.415	1.980	17,0	33.660
X	85.361	2.845	15,3	43.529
XI	63.742	2.125	13,2	28.050
XII	80.538	2.685	10,1	27.119
XIII	101.589	3.386	10,8	36.569
XV	70.791	2.360	10,6	25.016
XVI	66.632	2.221	13,1	29.095
XVII	33.059	1.102	15,0	16.530
XVIII	63.389	2.113	13,1	27.680
XIX	85.228	2.841	18,4	52.274
XX	69.299	2.310	20,2	46.662
total	*1.319.207*	*43.974*		*623.396*

4 Application of the Life Cycle Assessment (LCA) methodology

Life cycle assessment (LCA) is proposed as a technical tool for measuring impacts on the environment and their reduction, because by applying such approach, priorities can be identified more easily and policies can be targeted more effectively so that the maximum benefit for the environment is achieved relative to the effort expended [13].

The impact categories related to transportation emissions are:

- global warming, acidification and eutrophication due to CO, CO_2, NO_x and particulate emissions in air;
- human health due to CO, CO_2, NO_x and particulate emissions in air;
- natural resources depletion due to fuel consumption.

The total emissions per year are reported in Table 11, considering the current and the alternative scheme respectively. Adopting the Eco-indicator 99 method, the emissions have an impact on the ecosystem, measured by the Potentially Disappeared Fraction (PDF), on human health, evaluated by Disability-adjusted Life Years (DALY) and on natural resources depletion, measured in MJ [14]. The impact categories are weighted, assuming a priority factor (PF). Thus, for each indicator, an impact factors for 1 kg of substance have been considered

Table 11: Total emissions per year for C&D waste transportation in the current and the alternative scheme.

Current scheme					
vehicle	CO *kg*	CO_2 *kg*	NO_X *kg*	particulate *kg*	fuel *kg*
3,5-t	18.398	6.314.242	12.737	1.742	1.820.244
Alternative scheme					
3,5-t	5.191	1.781.380	3.593	491	513.529
44-t	4.264	1.270.483	19.949	262	170.561
total	*9.455*	*23.542*	*23.542*	*753*	*684.090*

Table 12: Impact factors of considered indicators for 1 kg of substance.

	PF	*CO*	*CO_2*	*NO_X*	*particulate*	*fuel*
PDF	*400*			*1,11E-03*		
DALY	*400*		*1,36E-05*	*5,76E-03*		
MJ	*200*					*7,02E-04*

Table 13: Ecopoints 99, referring to total emissions per year.

	Ecop/DALY	Ecop/PDF	Ecop/MJ	Ecop/Total
current	63.696	5.655	255.562	324.914
alternative	70.843	10.453	96.046	177.342
% variation	*+11,22%*	*+84,82%*	*-62,41%*	*-45,4%*

(Table 12). The Ecopoints 99 (Table 13) give a synthetic evaluation of the impacts in the current and in the alternative transportation scheme, referring to total emissions per year.

In general a overall improvement in environmental impact is achieved by adopting the alternative transportation scheme. The Ecop/PDF worsening is due to the increasing of NO_x emission from the 44-t vehicles. This result could be overcome by the application of the Euro 5 standards on emissions reduction, considering the restricted limits: 180 mg/km (20% reduction of emissions in comparison to the Euro 4 standard).

5 Conclusions

The use of a LCA model for analysing two scenarios makes it possible to provide quantitative and qualitative information both on the overall and particular environmental performance. LCA can identify not only the best scenario, but also the analytical contribution of each emission operations to the overall environmental performance of the system.

In particular, in this case study, it has been possible to investigate how an alternative C&D waste transportation affected environmental impact.

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