Assessment of alternative strategies for the management of waste from the construction industry

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Keywords: Construction and Demolition waste, Life Cycle Assessment, waste management

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The rapid growth of the construction industry worldwide during the past decades has resulted to an enormous increase of the produced Construction and Demolition Waste (CDW) quantities globally. In particular, the CDW waste stream constitutes the largest stream within the European Union (EU). CDW is generated from the construction, renovation, repair and demolition of structures, such as residential and commercial buildings, roads, bridges, etc. To that end, the composition of CDW waste varies for these different activities and structures. Often, it contains bulky and heavy materials, including concrete, wood, asphalt, gypsum, metals, bricks, glass, plastics, etc. All these different materials need to be managed in an environmentally sound and economic feasible manner. In this paper, alternative CDW management strategies are compared with the use of Life Cycle Assessment tool, taking into account environmental criteria, such as energy

consumption, global warming, depletion of abiotic resources and dispersion of dangerous substances. For the needs of the study, the SimaPro software package and the Ecoinvent v.3 Life Cycle Inventory database are used. The strategies that are considered in the framework of the present work are reuse, recycling, incineration and disposal of different waste sub-streams of CDW.

Keywords: Construction and Demolition Waste, Life Cycle Assessment, Life Cycle Inventory, Impact Assessment

Introduction

Construction and demolition wastes (CDW) constitute nowadays the largest by quantity fraction of solid wastes in Greece, as well as in other countries, especially in urban areas. In addition, it is widely accepted that the particular waste stream contain dangerous materials for the environment, such as insulating materials, plastic frames of doors and windows etc . Uncontrolled dispose of C&D waste has as a consequence long-term pollution costs, resource overuse and wasted energy (Moussiopoulos, 2009). Notwithstanding the massive volume of rejected building materials, as well as their relevant economic value and burden to the natural environment, none integrated management policy for such materials at the end of their useful life has been implemented yet in Greece (Aidonis et al., 2008).

In quantitative terms, the stream of C&D waste constitutes a significant proportion of all wastes within the EU-25, since the total amount generated is estimated to be roughly 180 million tones per year (excluding earth and excavated road material) (EC, 2000). Despite the significance of this particular stream of waste, in many countries there is a lack of accurate information on the field, as C&D waste is not studied separately from the rest municipal solid waste (MSW) stream (Dorsthorst and Kowalczyk, 2002).

Greece is among the countries (Bulgaria, Latvia, Hungary, Lithuania, Poland, Slovakia) that indicates very low levels of production of CDW (below 500 kg per capita in year), based on estimates made by the European Commission. More specifically, the CDW production in Greece that is managed through licensed infrastructure is estimated in the order of 0,37 tons per capita per year. However, according to the European Commission and the relevant Framework Contract on the Sustainable Management of Resources, this figure is underestimated, as a realistic value may reach 0,94 tons per capita per year. According to experts, the very low amounts listed are due to lack of control by the public authorities, which results into such inaccurate reports (EC, 2011).

Up to recently, the most common practice in the field of CDW management was to discard all waste materials and debris to landfills, frequently in the same landfills that were used for the disposal of MSW (Garrido et al., 2005). This practice cannot in any case be considered as a proper management practice for end-of-life building materials. Even worse, there are many cases reported where C&D waste ended up in uncontrolled open dumps, not taking into account the severe burden imposed upon the environment (Fatta et al., 2003). The environmental and health impacts of such disposal and treatment methods for C&D waste include apart from the aesthetic degradation, soil and water contamination, air pollution as a result of fires, reduced property values, destruction of open spaces and landscape blight (El-Haggar Salah, 2007). In addition, heaps of C&D waste may include asbestos waste, which poses a significant health risk, especially in building sites which are transformed into playgrounds and residential buildings (Hendricks et al., 2000).

Adopting the hierarchy of alternative waste management practices, disposal of CDW is located at the base of the pyramid and is the least preferred management option of end of life materials, following the avoidance, reduction, reuse and recycling (Blengini, 2010). CDW stream is characterized by high recoverability rate, since the recycling capability reaches 80 % (Bossink and Brouwers, 1996). To that end, it should be noted that there are countries with significant achievements in this area, such as Denmark, the Netherlands and Belgium that exceed the 80 % of recycling rate (Erlandsson and Levin, 2005). The best recycling practices are achieved in cases of lack of raw materials and disposal sites (Lauritzen, 1998).

Furthermore, recycling is an important aspect for maintaining areas for future urban development, as well as the development of local environmental quality (Kartam et al., 2004). Along with recycling practices, reuse can also be applied. For example, inert uncontaminated building materials at the end of their life can be used as filling materials for rehabilitation purposes (Poon et al., 2001). In this paper, alternative CDW management practices are compared with the use of Life Cycle Assessment tool, taking into account environmental criteria, such as energy consumption, global warming, depletion of abiotic resources and dispersion of dangerous substances for a specific case study (residential building).

Materials and methods

Methodology

The LCA methodology has been adopted for the detailed environmental evaluation of various CDW management practices generated by the demolition of a five-storey building located in Thessaloniki, Greece (Table 2). LCA (According to ISO 14040) comprises of four major stages: (i) Goal and Scope Definition, (ii) Life Cycle Inventory (LCI), (iii) Life Cycle Impact Assessment (LCIA) and (iv) Visualisation of the results (PRe Consultants, 2010a).

The “Goal and Scope Definition” phase defines: (i) the overall objectives, (ii) the boundaries of the system under study, (iii) the sources of data and (iv) the functional unit to which the achieved results refer to. Furthermore, the “LCI” consists of a detailed compilation of all the environmental inputs (material and energy) and outputs (air, water and solid emissions) at each stage of the life cycle (JRC, 2011). In addition, the “LCIA” phase aims at quantifying the relative importance of all environmental burdens obtained in the “LCI” stage by analyzing their influence on the selected environmental effects.

The general framework of an “LCIA” method (according to ISO 14042) is composed both of mandatory elements (classification and characterization) that convert “LCI” results into an indicator for each impact category and of optional elements (normalization and weighting) that lead to a unique indicator across impact categories using numerical factors based on value-choices (PRe Consultants, 2010b). In this light, as there is neither consensus on weighting nor on the optimal weighting method to adopt, the LCIA phase was initially focused on the characterization step. To that end, eight indicators were considered (Table 1).

Table 1: Environmental Indicators of CML method (PRe Consultants, 2010c).

CED:	Cumulative Energy Demand	Indicator relevant to the total energy resource consumption according to Boustead
GWP:	Global Warming Potential	Indicator relevant to the GH effect according to IPCC
ODP:	Ozone Depletion Potential	Indicator relevant to the stratospheric ozone depletion phenomenon;
AP:	Acidification Potential	Indicator relevant to the acid rain phenomenon
EP:	Eutrophication Potential	Indicator relevant to surface water eutrophication
POCP:	Photochemical Ozone Creation Potential	Indicator of photo-smog creation
HTTP:	Human Toxicity Potential	Indicator of consequences of toxic substances
ADF:	Abiotic Depletion Factor	Indicator of fossil fuel extraction

All above mentioned indicators –except from the one related to energy demand– are contained in the CML method. According to the ISO 14040 standard, in the last step of an LCA study, the results from the LCI and LCIA stages need to be interpreted in order to identify hot-spots and compare alternative practices. SimaPro 7 software application was used as a supporting tool in the framework of the present work in order to implement the LCA model and carry out the assessment.

The study focused on the end of the life cycle of a real-world residential building, with emphasis on its end-of-life management. Inventory data from previous research were used as input data for the LCA modeling herein conducted, towards improving the local representativeness of the achieved results.

Functional unit and system boundaries

As a case study, the demolition of an old five-storey building located in the city of Thessaloniki, Greece (functional unit) was adopted. Table 2, presents indicatively the constructional characteristics of the building under consideration. The analytical constructional details of the five-storey building were presented elsewere (Banias et al., 2009).

Table 2: Building's characteristics.

Building features	
Number of floors:	5
Number of flats:	15
Total building area:	1020 m^2
Construction year:	2005
Location:	Municipality of Kalamaria, Thessaloniki

Figure 1a illustrates the system's boundaries. It is clearly depicted that only the last phase of building's life cycle (end-of-life phase) has been included in the LCA model. Wastes produced by demolition include metals (steel, aluminum, copper, and zinc), inert wastes (tiles, concrete, bricks, ceramic materials, stones, clinker), wood, plaster, plastic (PVC), glass, and insulation materials. Hence, the wastes produced by this demolition (system boundaries) are summarised in Table 3 (Banias et al., 2011).

Table 3: CDW quantities.

Material	Quantity (t)	Material	Quantity (t)
Concrete	1778,8	Plastic (pipes)	0,3
Bricks	90,3	Aluminum	8,6
Ceramic tiles	15,8	Iron and steel (heating coil)	1,1
Sanitary ware	1,4	Iron and steel (boiler)	0,3
Marbles	8,4	Iron and steel (pipes)	1,5
Wood	4,1	Cables	0,2
Glass	`2,5	Insulation materials	1,5

System expansion

Figure 1b illustrates system's expansion. It can be clearly seen that by extending the system boundaries the following processes are also taken into account: (a) The mining of raw materials, (b) The transfer of the materials and (c) Production and manufacturing processes, since procedures of reuse, recycling or incineration did not take place. In this light, towards disclosing the environmental gain achieved, through the proposed CDW management practices, the environmental burdens of the production processes were excluded from the LCA model (Kuikka, 2012).

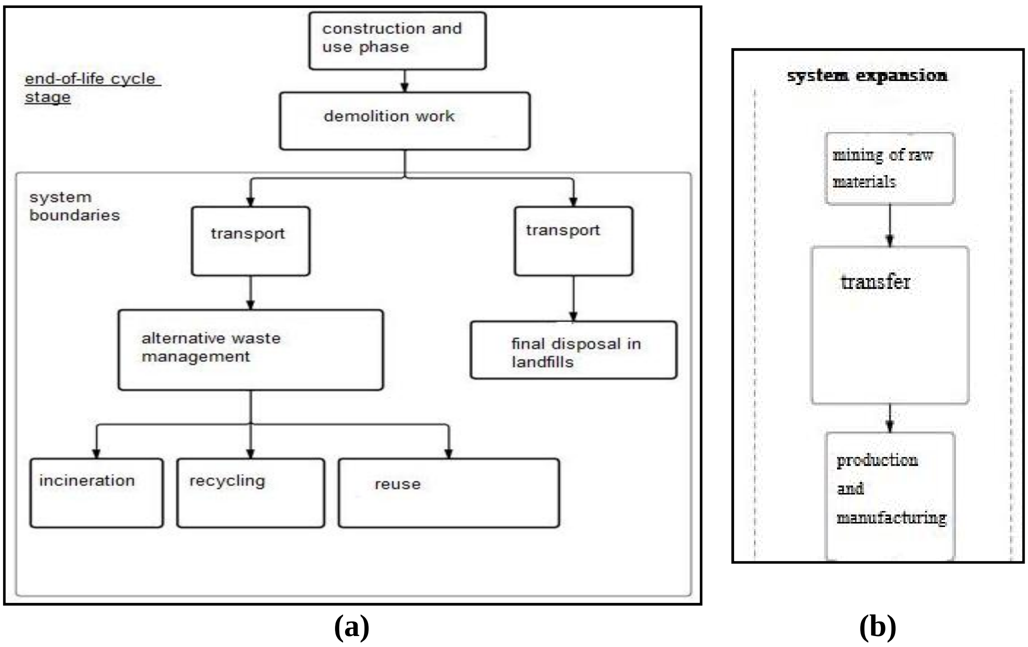


Fig. 1. System boundaries (a) and expansion (b).

Inventory analysis

Towards optimal CDW management, nine practices have been considered. The proposed CDW management practices represent the different possible strategies that can be adopted by the stakeholders of construction industry (i.e. constructors, engineers, public authorities, etc). Each CDW management practice has different environmental, economic, and social consequences. The nine CDW management practices (called PI–P9) are presented in the material to follow. It should be highlighted that all CDW management practices are realistic and technically possible. The philosophy of the proposed CDW management practices is focused towards reuse, recycling, energy recovery and final disposal in landfills (Roussat et al, 2008).

Practice 1 (P_1): In this practice, the five-storey building is demolished without sorting of the different materials. The wastes of this demolition are dumped to landfills.

Practice 2 (P_2): The five-storey building is also demolished without sorting of different constituents, but after demolition, the wastes go to a sorting platform for construction and demolition waste. After sorting of the different fractions of wastes, metals are recycled while all other categories of waste go to a landfill.

Practice 3 (P_3): In this practice, the five-storey building is also demolished without sorting and wastes go to the sorting platform. After sorting, metals are recycled and inert wastes are recovered in road engineering. Non-hazardous solid wastes (woods, plastics) are burned in an incinerator. Energy produced by incineration is recovered in electricity and in thermal power.

Practice 4 (P_4): The first step of this practice is the selective deconstruction of the five-storey building, i.e., all non-hazardous and hazardous components are removed before demolition of the building structures. Each waste type, except metals and glass, which are recycled, go to sanitary landfills. **Practice 5 (P_5):** As in Practice 4, the first step is the selective deconstruction of the five-storey building before demolition. Inert wastes are recovered in road engineering. Metals, glass and insulation are recycled. Wood wastes are used as fuel for district heating, and other non-dangerous wastes go to a landfill.

Practice 6 (P_6): The difference between this practice and Practice 5 is that inert wastes are used to produce new concrete blocks as raw material. The making of concrete blocks with recycled aggregates requires the addition of natural aggregates and increasing of the cement content in relation to standard concrete block composition, in order to have the same technical characteristics of usual concrete blocks.

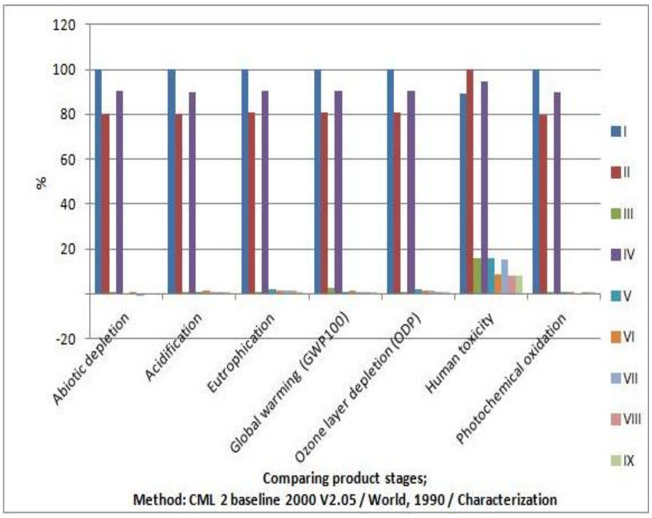
Practice 7 (P_7): The first step of this practice is the selective deconstruction of each building before demolition of their structures. Inert wastes are recovered for use in aggregates for road engineering. Metals, wool, PVC and insulation are recycled. Wood wastes are used to make particle board.

Practice 8 (P_8): The only difference between this practice and Practice 7 is that inert wastes are used to produce new concrete blocks, as in the Practice 6.

Practice 9 (P_9): This practice is the same as Practice 7, except that wood wastes are used as fuel for district heating.

Results and Discussion

In order to investigate the optimal CDW management strategy ("LCIA" stage) towards the minimisation of the environmental burden, a comparative analysis of the nine proposed practices was carried out with the use of SimaPro software package and the Ecoinvent v.3 Life Cycle Inventory database. Figure 3a, illustrates the environmental impact of the proposed CDW management practices with respect to the seven environmental indicators introduced by CML method, while its numerical results are presented in Table 4.



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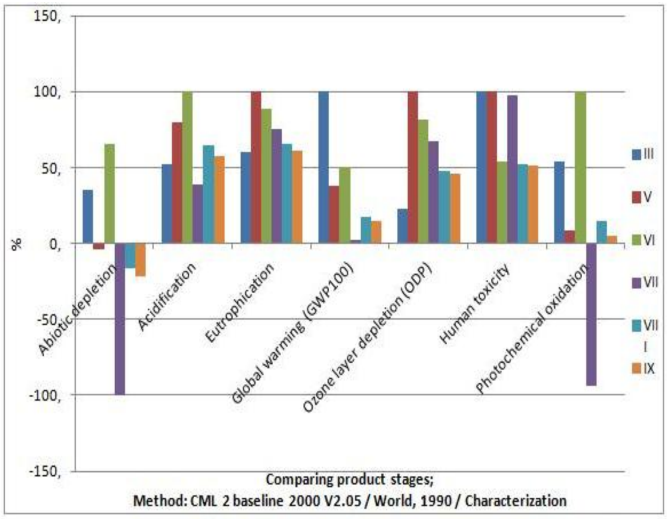

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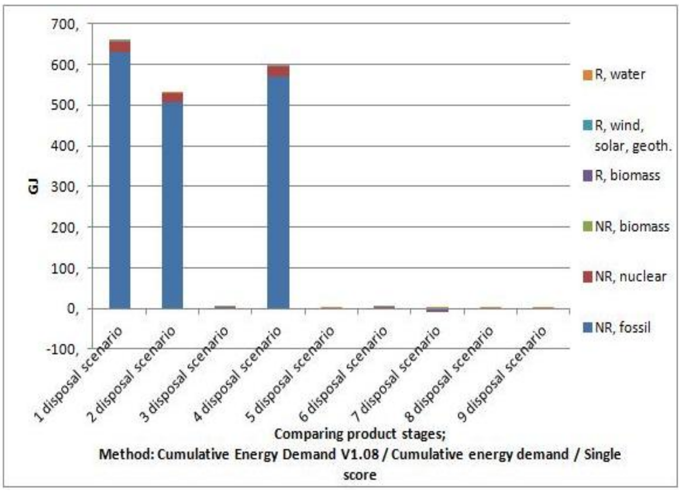
Fig. 3. (a) CDW practices' Environmental Impact, **(b)** Environmental Impact of P_3, P_5, P_6, P_7, P_8 and P_9.

Table 4: Numerical results of CDW practices' Environmental Impact.

CDW Management Practice	Environmental indicator						
	ADF Kg Sb eq	**AP** Kg SO_2 eq	**NP** Kg PO_4 eq	**GWP_{100}** Kg CO_2 eq	**ODP** Kg CFC-11eq	**HTP** Kg 1,4-DB eq	**POCP** Kg C_2H_4 eq
P_1	286	199	55,9	$3{,}98 \cdot 10^4$	0,006	$1{,}71 \cdot 10^4$	6,42
P_2	229	160	45,1	$3{,}2 \cdot 10^4$	0,005	$1{,}92 \cdot 10^4$	5,13
P_3	1,02	1,32	0,575	918	$2{,}93 \cdot 10^{-5}$	$3{,}03 \cdot 10^3$	0,02
P_4	258	179	50,5	$3{,}6 \cdot 10^4$	0,005	$1{,}81 \cdot 10^4$	5,77
P_5	-0,12	2,03	0,95	345	0,0001	$3{,}03 \cdot 10^3$	0,0039
P_6	1,92	2,54	0,845	461	0,0001	$1{,}64 \cdot 10^3$	0,04
P_7	-2,92	0,994	0,715	24,6	$8{,}61 \cdot 10^{-5}$	$2{,}95 \cdot 10^3$	-0,04
P_8	-0,47	1,64	0,622	161	$6{,}15 \cdot 10^{-5}$	$1{,}58 \cdot 10^3$	0,007
P_9	-0,63	1,45	0,58	137	$5{,}85 \cdot 10^{-5}$	$1{,}56 \cdot 10^3$	0,002

It can be clearly seen that P_1, P_2 and P_4 have the most severe environmental impact compared to the other ones. Thus, in order to obtain a clearer view of the CDW management practices' environmental impact a comparative graph was carried out with the later practices excluded (Fig.3b). In addition, the results for the "CED" indicator are presented in Fig. 4a while its numerical results are presented in Table 5.



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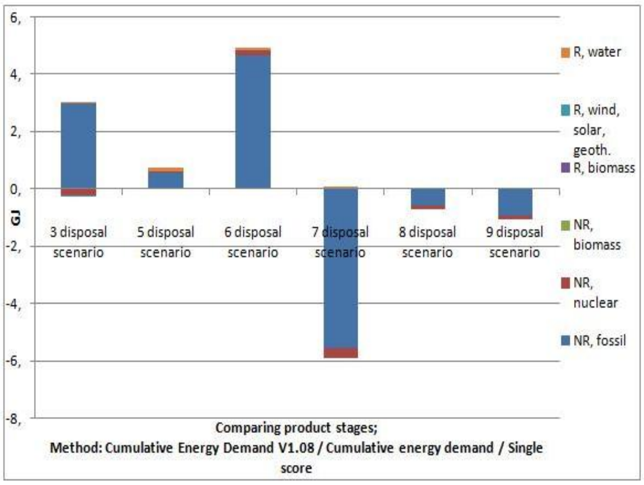

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Fig. 4. (a) CDW practices' Environmental Impact for the "CED" indicator, **(b)** Environmental Impact of P_3, P_5, P_6, P_7, P_8 and P_9 for the "CED" indicator,

Table 5: Numerical results of CDW practices' Environmental Impact for the "CED" indicator.

CDW Management Practice	Environmental indicator						
	Average MJ	**Nonrenewable-fossils** MJ	**Nonrenewable-nuclear** MJ	**Nonrenewable-biomass** MJ	**Renewable-biomass** MJ	**Renewable-wind, solar, geothermal** MJ	**Renewable-water** MJ
P_1	$6{,}62\cdot10^5$	$6{,}29\cdot10^5$	$2{,}66\cdot10^4$	1,08	892	229	$4{,}79\cdot10^3$
P_2	$5{,}33\cdot10^5$	$5{,}07\cdot10^5$	$2{,}1\cdot10^4$	0,878	721	185	$3{,}88\cdot10^3$
P_3	$2{,}75\cdot10^3$	$2{,}98\cdot10^3$	-236	0,00448	3,38	-7,98	7,02
P_4	$5{,}99\cdot10^5$	$5{,}7\cdot10^5$	$2{,}39\cdot10^4$	0,986	809	207	$4{,}35\cdot10^3$
P_5	723	568	17,1	0,033	21,1	5,74	111
P_6	$4{,}94\cdot10^3$	$4{,}64\cdot10^3$	191	0,026	16,8	4,74	86,5
P_7	$-5{,}8\cdot10^3$	$-5{,}55\cdot10^3$	-341	0,02	13,2	3,78	66,9
P_8	-661	-585	-127	0,013	8,47	2,7	39,3
P_9	$-1\cdot10^3$	-935	-134	0,012	8,17	2,57	38,4

It should be highlighted that SimaPro software has the ability to visualize the Environmental Impact through the "Network Process". The "Network Process" depicts the environmental impact of CDW management practices graphically. To that end, for each CDW management practice, graphical network visualization has been created. Indicatively, Figure 5 illustrates the "Network Process" for P_9 the "CED" environmental indicator. It should be noted that red lines indicate the environmental burdens, while green lines depict the environmental benefits.

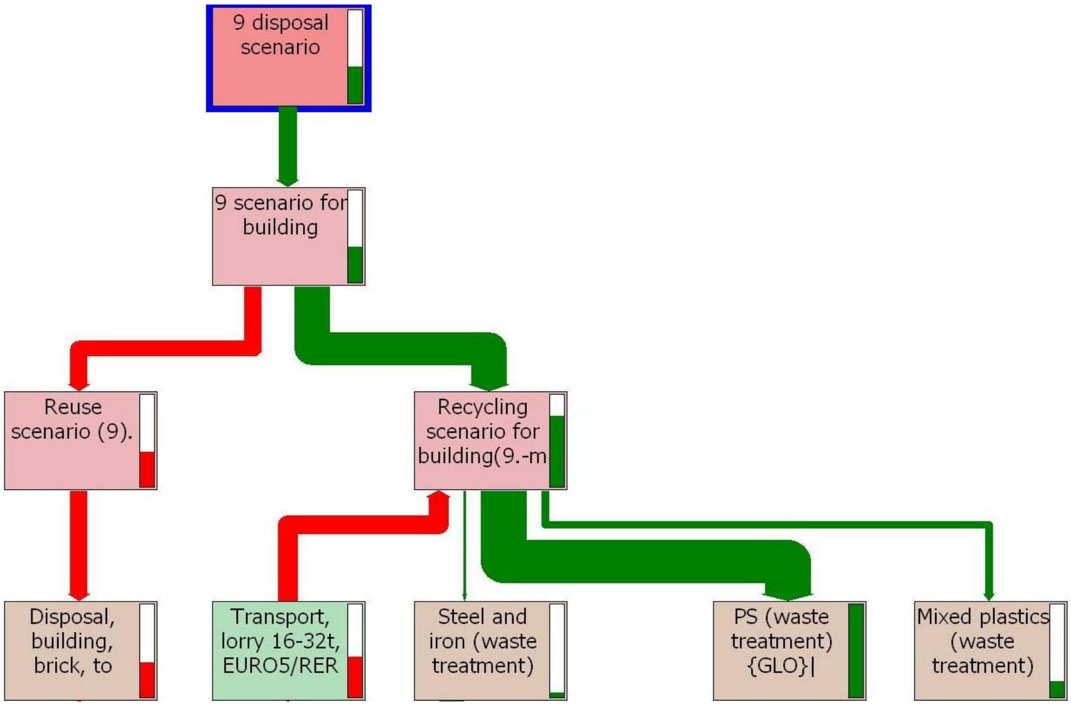

Fig. 5. Environmental Impact of P_9 for the "CED" indicator.

It can be easily concluded that P_7 appears to be highly robust, as it is the best available CDW management practice for five (5) out of eight (8) CML's environmental indicators (photochemical smog, climate change, acidification, depletion of abiotic resources and cumulative energy demand). Furthermore, P_7 ranks fourth (4) for the three remaining CML's environmental indicators (human toxicity, reduce of stratospheric ozone and eutrophication). P_9 also appears to be stable, as it ranks first (1) for indicators of eutrophication and human toxicity. The uncontrolled dumping of CDW (P_1) can be characterized as the practice with the most severe environmental burden. Table 6 depicts the CDW management practices ranking.

Table 6: Ranking of waste management practices.

Environmental indicator	Ranking								
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Photochemical ozone creation	P_7	P_9	P_5	P_8	P_3	P_4	P_2	P_6	P_1
Human toxicity	P_9	P_8	P_6	P_7	P_5	P_3	P_1	P_4	P_2
Ozone depletion	P_3	P_9	P_8	P_7	P_6	P_5	P_2	P_4	P_1
Global warming	P_7	P_9	P_8	P_5	P_6	P_3	P_2	P_4	P_1
Eutrophication	P_9	P_3	P_8	P_7	P_6	P_5	P_2	P_4	P_1
Acidification	P_7	P_3	P_9	P_8	P_5	P_6	P_2	P_4	P_1
Abiotic depletion	P_7	P_9	P_8	P_5	P_3	P_6	P_2	P_4	P_1
Cumulative energy demand	P_7	P_9	P_8	P_5	P_3	P_6	P_2	P_4	P_1

It should be noticed that Deconstruction (or selective demolition) is a vital step towards the sustainable CDW management. It goes without saying that the sorting of the different materials it is crucial for the effectiveness of an optimal CDW management practice. To that end, a CDW management practices which involves: (i) the reuse of inert materials (i.e. in road engineering), (ii) the reuse of wood for particle board production, (iii) as well as the recycling of metals, glass, plastic and insulating material can be considered as the optimal waste management strategy

Conclusions

CDW can be considered as a top priority waste stream, with respect to the strategy for the waste management followed by the European Union (EU Waste Strategy). It should be emphasised that, the promotion of deconstruction (selective demolition), the use of environmental friendly building materials, the replacement of hazardous substances and materials, the development of Construction Materials' secondary market and the adoption of stricter legislation framework are measures that need to be considered towards emerging the principles of sustainable development in the construction industry.

A waste management strategy is not effective without a good sorting of different wastes. For inert wastes, recovery in aggregates for road engineering is a better solution than the use of these aggregates to produce concrete blocks. The poor technical characteristics of recycled aggregates that are involved in the making of concrete blocks are not environmentally and economically efficient in comparison to concrete blocks produced with natural aggregates.

Local authorities will be able to use the results of this study to provide guidelines for future demolition of buildings. In addition, the urban community could use the environmental indicators and the method that were used in this study to choose other sustainable strategies within the community.

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References

Aidonis D., 2009. Applied Operations Research Methodologies for the Optimal Design and Operation of Reuse and Recycling Networks of Construction and Demolition Materials. Ph.D. Thesis. Department of Mechanical Engineering, Aristotle University Thessaloniki.

Banias G., 2009. Development of a System for the Optimal Construction and Demolition Waste Management. Ph.D. Thesis. Department of Mechanical Engineering, Aristotle University Thessaloniki.

Banias G., Achillas Ch., Vlachokostas Ch., Moussiopoulos N., Papaioannou I., 2011. A web-based Decision Support System for the optimal management of construction and demolition waste. Waste Management 31, 2497-2502.

Blengini GA., Garbarino E., 2010. Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix. Journal of Clearer Production 18 (10-11), 1021-1030.

Dorsthorst, B., Kowalczyk, T., 2002. Design for recycling. Design for deconstruction and materials reuse. In: Proceedings of the International Council for Research and Innovation in Building Construction (CIB) Task Group 39 – Deconstruction Meeting, Karlsruhe, 9 April 2002, pp. 70–80.

EC (European Commission), 2011. Directorate-General Environment, Service contract on management of construction and demolition waste, Final report task 2, February.

El-Haggar Salah M., 2007. Sustainability of Construction and Demolition Waste Management, Sustainable Industrial Design and Waste Management Cradle-tocradle for Sustainable Development, pp. 261–292 (Chapter 8).

Erlandsson M., Levin P., 2005. Environmental assessment of rebuilding and possible performance improvements effect on a national scale. Build. Environ. 40 (11), 1459–1471.

Esin T., Cosgun N., 2007. A study conducted to reduce construction waste generation in Turkey. Build. Environ. 42 (4), 1667–1674.

Fatta D., Papadopoulos A., Avramikos E., Sgourou E., Moustakas K., Kourmoussis F., Mentzis A. and Loizidou M., 2003. Generation and management of construction and demolition waste in Greece – an existing challenge. Resour. Conserv. Recycl. 40, 81–91.

Garrido E., Calno F., Ramos A.F., Zamorano M., 2005. Methodology of environmental diagnosis for construction and demolition waste landfills: a tool for planning and making decisions. Environ. Technol. 26, 1231–1241.

Hendricks F., Nijkerk A., Van Koppen A., 2000. The Building Cycle. Aeneas, The Netherlands.

Bossink B.A.G., Brouwers H.J.H., 1996. Construction waste: quantification and source evaluation. J. Construct. Eng. Manage. 122 (1), 55–60.

Joint Research Center (JRC) Scientific and Technical Reports, 2011. A technical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) for waste experts and LCA practitioners, Supporting Environmentally Sound Decisions for Waste Management.

Kartam N., Al-Mutairi N., Al-Ghusain I., Al-Humoud J., 2004. Environmental management of construction and demolition waste in Kuwait. Waste Manage. 24, 1049–1059.

Kuikka S., 2012. LCA of the Demolition of a Building. Ph.D. thesis, Chalmers University of Technology, Department of Energy and Environment, Division of Environmental System Analysis, Gothenburg.

Lauritzen E.K., 1998. Emergency construction waste management. Safety Sci. 30, 45–53.

Moussiopoulos N., Banias G., Aidonis D., Anastaselos D., Achillas Ch., Iakovou E., Papadopoulos A., Vlachokostas Ch., 2009. Development of a web based application for the optimal demolition waste management in the Region of Central Macedonia. In: Lekkas, T.D. (Ed.), Proceedings of the 11th International Conference on the Environmental Science and Technology – CEST2009, Chania, Crete Island, Greece, 3–5 September, pp. 954–961.

Poon C., Yu Ann T., Ng L., 2001. On-site sorting of construction and demolition waste in Hong Kong Resources. Conserv. Recycl. 32 (2), 157–172.

Product Ecology Consultants (PRe Consultants), 2010a. Introduction to LCA with SimaPro 7.

Product Ecology Consultants (PRe Consultants), 2010b. SimaPro 7 Tutorial.

Product Ecology Consultants (PRe Consultants), 2010c. SimaPro Database Manual-Methods Library.

Roussat N., Dujet Ch., Méhu J., 2008. Choosing a sustainable demolition waste management strategy using multicriteria decision analysis, Waste Management 29, pp.12-20.