LCA OF DRINKING AND WASTEWATER TREATMENT SYSTEMS OF BOLOGNA CITY: FINAL RESULTS.

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Abstract
A pilot study to apply LCA methodology to domestic water cycle of Bologna city is in course of completion. The activity is being carried out within the AQUASAVE project, funded by a LIFE-ENVIRONMENT action of the European Union. The LCA study objective is to develop a model that will allow to compare the overall environmental impact of the “existing scenario” of the drinking and wastewater treatment systems of Bologna metropolitan area to the “innovative one” tested in AQUASAVE. The final TEAM36LCA model of the "existing scenario" has been completed.

In this paper the methodological approach, the limits and advantages of LCA methodology when applied to urban water cycle and the final results of the study are discussed.

Life cycle assessment, LCA, urban water cycle sustainability

INTRODUCTION
As part of AQUASAVE project, funded by the European Union in the framework of the LIFE-ENVIRONMENT action, an assessment of the environmental sustainability of innovative techniques of water consumption reduction, rain water harvesting and grey water reuse in a residential building of Bologna city is in progress. The aim of AQUASAVE project is to design and build an apartment house in Bologna, to demonstrate through the introduction of appropriate devices and technologies, the possibility to save up to 50% of drinking water.

For verifying if substantial environmental improvements can be obtained, a comparison between the “existing” urban water cycle and an “innovative” one, in which AQUASAVE proposed technologies are applied, is in course of completion. The Life Cycle Assessment (LCA) methodology has been adopted, due to its capacity of quantitatively assess the life cycle of products and services. The analysis of the “existing” scenario has been completed and is presented in this paper. The study has been carried out with the full co-operation of management and engineers of SEABO, the municipal water firm of Bologna city which is partner of AQUASAVE project.

METHODOLOGY
The LCA study has been conducted according to ISO 14040 standards. The goal has been the evaluation of the environmental benefits and burdens of introducing innovative techniques in the AQUASAVE demonstration building. To reach this goal the “existing scenario” of drinking water production and distribution and of waste water treatment for the entire Bologna district, has been analysed in detail. The study has enabled the identification of the main environmental burdens, helping in proposing potential improvements.

The analysis of the functions of the studied system suggested the adoption of the following functional unit “the supply of a quantity of water of suitable quality for
performing all domestic activities to one person living in Bologna and the treatment of resulting wastewater”. According to the actual consumption estimations the reference flux has been assumed to be 180 liters per day (corresponding to 65.7 m³ per year).

Fig. 1 shows the adopted system boundaries. The system includes all the processes for the distribution and treatment of drinking and waste water, the production processes of chemicals, electric energy and materials used in water treatment plants, including their transport to the final use location.

The contribution to Life Cycle Inventory of all equipment, waterworks, buildings and capital goods required in the system for processing and distributing drinking water and for treating wastewater has not been included in the analysis, as they are supposed to remain unchanged both in “existing” and in the “innovative” scenario.

To model the entire studied system and perform all the inventory and impact assessment calculation the TEAM 3.0 software, developed by Ecobilan, was used.

The data have been collected from various sources. On site specific data have been gathered for all the drinking water treatments and waste water treatment plant (WWTP) processes, with the support of SEABO technicians. The main data collection method for chemicals was by identifying the specific manufacturer of the commercial product. The processes involved in chemicals manufacture were identified through these contacts and as much data as possible regarding the manufacturing process was obtained. Where specific data were not available, reference was made to TEAM 3.0 database or to relevant scientific literature.

As the studied system is very complex, several assumption were needed to model it. In Bologna metropolitan area there are six sources of drinking water (a superficial one and five wells): It was decided to consider the water entering in the “AQUASAVE” residential building as a weighted average of the six sources. It was assumed that the drinking water provided to the apartments is all discharged to wastewater collectors and treated inside the wastewater treatment plant.

A number of chemicals are used in the processes: after analysing the products Material Safety and Data Sheets (MSDS), we verified that no toxic substances are involved and decided to exclude from the inventory, substances whose cumulative mass were not greater than 5% of the sum of the input masses (water excluded). This assumption has been validated by the results of the analysis.

**SYSTEM DESCRIPTION**

Bologna is an Italian city with 380,000 inhabitants which extends on km² 140 area.
Bologna drinking water comes from five groundwater sources and a superficial one (Setta river). The contribution of groundwater sources to the total drinking water mass fed to the network in one year is about 60%. The groundwater treatment processes are very simple: a disinfection by mean of ClO₂ is in general sufficient. The water of some well needs a preliminary sand filtration and activated carbon adsorption is needed.

Fig 2 shows the treatment processes of Setta river plant. This plant works continuously, with a flowrate that changes seasonally depending on the water level in the river. The Bologna distribution net is very complex and is fed by two water reservoirs each of m³ 40.000 located at the opposite limits of the city and connected by a backbone piping. Near the two reservoirs sodium hypochlorite is added as required to ensure the net disinfection.

The Bologna sewer net collects domestic wastewater, as well as urban runoff and effluents coming from some industries in the area. The most part of the rain water collected by the sewer net reaches the wastewater treatment plant; in case of important storms, however, numerous weirs, dispersed in the sewer system, discharge the water directly into superficial water bodies. The weirs are designed to ensure the proper dilution factor of the effluents for respecting the allowed concentration of contaminants.

Fig. 3 shows the WWTP processes. The plant has a sludge incinerator in which the combustion heat is recovered and used to increase the input sludge temperature. The
effluents of the plant are treated water discharged to Canale Navile; ashes and sludge (only when the incinerator is out of order) sent to landfill; sand, oil and material from straining directly sent to Municipal Solid Waste incinerator; airborne emissions due to sludge incineration and biogas combustion. The plant has an odour treatment line: the air over the main treatment stages is collected and treated by means of a bio-filter.

ALLOCATION
As suggested by ISO 14040 standards, where possible the allocation has been avoided. Anyway the Bologna WWTP treated in the reference year almost 58 million of cubic meters of water, of which roughly 14% was rain water, 64% domestic wastewater and 22% industrial wastewater. So, as the urban runoff and the industries connected to the sewer net were not included in the analysed system, the impact of WWTP processes was allocated on mass. Moreover, it was decided to do not consider the presence of metals (zinc, copper, lead, chromium, nickel) in the treated effluent, in the sludge and in the incinerator emissions, as they can be clearly related to urban runoff and industries effluents. Substances clearly related to domestic wastewater (nutrients, tensides, suspended solids, COD, TOC) were included in the environmental effect analysis.

RESULTS
In this study several environmental impact categories have been investigated and the processes responsible for the main environmental loads have been identified. The system has been divided in seven main stages. The stage “distribution” includes the impacts of energy consumption for pumping the water in the net and the sodium hypochlorite consumption that is used for net disinfection; the stage “landfill (special waste)” takes in account the impacts of disposal the ashes coming from the Seabo sludge incinerator and the sludge from Setta river plant in a landfill for special, non dangerous wastes; when Seabo incinerator is not operating, WWTP sludge is disposed in a landfill for urban wastes (stage “landfill”); materials coming from WWTP straining, grit chamber and deoiler are sent to Municipal Solid Waste Incinerator (stage “incinerator”).

Fig 4 shows the energy indicators for the system. It can be observed that the main energy consumption is related to drinking water treatments and is due to electrical energy used for water pumping (about 65% of the total energy consumption); the energy used in WWTP is mainly electrical energy used on site as well. Looking at the inventories tables it is possible to underline that:
• 10% of the primary energy extracted from the environment is required for chemicals production;
• the contribution of transport phases (fuel production and burning) to the total energy use is irrelevant.

Fig. 5 shows that CO₂ and methane emissions are the main contributors (99%) to greenhouse effect. Both species are mainly released in the electric energy production processes; the production of the electric energy used on site is responsible for 93% of the total impacts. The contribution of chemical production is limited to few percent.

Fig 6 confirms that the dominant process is the electric energy production. This process in fact is responsible of 90% of the impacts, mainly trough the emissions of SOₓ and NOₓ (which together have 100% of the impacts). Chemicals manufacturing contribution is 4% of the effects in this category.
Fig 7 shows the contribution of different chemical species to photochemical oxidant formation. Electric energy production is still the dominant effect (90% of the effects for the electric energy used on site). Drinking water treatments are responsible of 60% of the impacts.

Fig 8 shows the environmental effect in the Aquatic toxicity categories. The effects have been quantified using USES 1998 method developed by CML (Netherlands). Anyway the analysis has been repeated applying several different methods (CML 1992, CST 1995 and USES 1 1994), in order to confirm the identification of the critical processes. Each method adopts different reference substances and different characterization factors, but nevertheless they all agree in identifying by far the electric energy production as the dominant process. The same procedure has been applied to human toxicity and terrestrial toxicity impact categories: the results were very similar.

Fig 9 shows that the main impacts are due to natural gas and oil consumption for electric energy production. Electric energy production causes 70% of the impacts. Chemicals production contributes with 10%, mainly for bauxite needed in the aluminium based flocculant production.

With regard to water eutrophication category, the discharge in the environment of the treated effluent is responsible, as can be guessed, for 100% of the impacts.
Fig 10 shows the impact of the selected reference flux on each environmental category divided by the impact of an average European inhabitant over one year (IVAM ER elaboration of CML 1992 method). Normalization reveals which effects are large and which are small in relative terms. With this approach the most relevant effect seems to be eutrophication. Anyway the relative contribution is in the order of 2%, indicating that a well managed WWTP reduces the eutrophication potential to an acceptable value compared to, for instance, the nutrient release in agricultural practices.

CONCLUSIONS
In this study the “existing scenario” for treatment and supply of drinking water and for treatment of wastewater in Bologna city has been analysed. By mean of environmental impact assessment categories well accepted at international level, the environmental critical processes have been identified. The production of electric energy mainly used for on site water pumping is by far the most relevant process in almost all impact categories. Nevertheless in absolute terms, the “energy content” of the water cycle (90 kWh per person per year) is not so impressive, being only a percentage of the electricity needed in an apartment. The discharge in the water body of the treated effluent is responsible for 100% of water eutrophication impacts. Looking at Fig. 10 the contribution of domestic water cycle when compared to the total contribution of one person is in the order of 2%, indicating that a well managed WWTP reduces the eutrophication potential to an acceptable value compared to an average emission of a European citizen. Chemicals production impact is in general low but not irrelevant: an accurate dosage can reduce the consumed quantity and consequently the actual impacts. Transport phases and the related fuel production are irrelevant in all environmental impact categories.

LCA results indicated that to further improve the environmental performances of the “existing” water cycle it is necessary to reduce the energy consumption, optimising design and operation of pumping devices.

On the other hand water is considered only a renewable natural resource in LCA: but if local conditions are considered the lowering of water-bearing stratum is the main responsible of the subsidence phenomenon that has originated a ground lowering of 5-6 centimetres per year in 34% of Bologna metropolitan area. Each action that brings to a more rationelle water use and causes a lower groundwater extraction should be carefylly evaluated. These considerations shall be taken in account in
weighting the environmental impact categories and in evaluating the suitability of innovative technologies for rainwater harvesting and grey water reuse.

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