Energy and Chemicals Consumption Evaluation in Water Treatment Plant

A comparative study between Bacau and Turin

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The total energy demand of water treatment plant Bacau (WTP Bacau) was evaluated at 239.94 MW h/y; in case of SMAT (Turin-lately) total energy demand of the plant was evaluated at 2.235,454.9 MW h/y; and 6.9% is for WT. Chemicals consumption, is relative and depends on raw water turbidity at WTP Bacau, during the winter period raw water is very clean and requires only a simple chlorination, on the other hand at SMAT chemicals consumption, is 5.325 t/y and 8.8% is used for water treatment process.

Keywords: water treatment, chemical consumption, energy consumption, carbon footprint

The production of drinking water from fresh surface water/groundwater involves several processes, energy consumption and chemical dosing, these should be considered in the choice of water treatment scheme to reduce environmental impact by applying the carbon footprint methodology, approach require the knowledge of each equipment in water treatment plant, energy consumption, material flows.

The specific purpose of the work is to make a comparative study regarding the chemical and energy consumption at two water treatment plants respectively water treatment plant Bacau, Romania and water treatment plant SMAT Turin, Italy and to see which have the significant impact on the environment and how can be reduce.

Water is one of the largest current and future global challenges. By 2050, world population will be increased from 7 to 9 billion. This enormous growth means that the need for water will increase by 50% if we continue to consume at the current rate (Ramboll Romania, 2012). Treatment of water-varies as to the source and type of water. For example, municipal waters, consist of surface water and ground water, and their treatment is to be distinguished from that of industrial water supplies. The main objective of water treatment is to deliver good quality drinking water to consumers. Making water drinkable means removing most of the organic components, inorganic and biological components found in water, resulting water according to national and international standards concerning drinkable water [1].

Water treatment plant Bacau

Bacau City is situated in the North-Eastern part of Romania, in historical Moldova Region and has a population of 144,304 inhabitants (2011 census). WTP Bacau manages the entire water cycle in the city of Bacau and processes a maximum flow rate of 1,400 m³/h raw water from Lake Poiana Uzului [2].

Source current system of water supply for the residents of the city of Bacau consists of double supply respectively, source of surface and groundwater. Surface water source is the Poiana Uzului Lake (is not affected by industrial pollution) and source of groundwater consist from a total of six collection fronts, which include small and medium depth wells located in the riverbed of Bistrita river which are limited and do not have potential for expansion and does not only partially ensure domestic and industrial consumption of water [2].

The main water treatment process it takes place by gravity, placing the entry point of raw water to the highest end of the plant, which will allow the water to revolve through the various treatment units, down into the treated water storage tanks, which it is approximately 9 m below [2].

Water treatment plant SMAT, Turin

On the other hand in case of WTP SMAT from Turin the things are different. TURIN is an important industrial city and cultural centre in northern Italy, capital of the Piedmont region, located mainly on the left bank of the Po River. With a area 130 Km² and a population of 870,702 inhabitants (2012 census). PO river- comes from Cotici Alps near the Italian border with French and flows into the Adriatic near Venice. Also it should be noted that the Po river is affected by the industrial pollution because it crosses Turin and other 4 cities, (Ferrara, Piacenza, Milano, Comacchio) [3].

The SMAT SpA, Turin Metropolitan Water Company, manages the entire water cycle in the city of Turin and its province, dealing with the drinking water, the water supply and wastewater treatment. The water treatment plants are considered 3, and are as follows: plant Po1, plant Po2, plant Po3. The first two plants came into operation as early as the first half of the ’60s and possess the same technological characteristics, as well as identical potential, equal to 500 l/s. The water treatment plant Po3 was designed a decade later, based on a forecast of the Plan of Aqueducts which attributed to Turin, for the year 2015, a population of 1,780,000 inhabitants: according to this projection was scheduled for Po3 a potential of 3000 l/s [3].

In systems Po1 and Po2, in fact, the treatment is divided into the following phases and in the WTP Po3 the system solutions used are different, extent which creates diversity in the early stages of treatment [3].

Experimental part

The concept of carbon footprint (CF), as a fundamental quantization parameter of carbon emissions measurement, captures the interest of policy makers,
businesses and consumers attention. Carbon footprint is the cumulative effect of various human activities on the environment of the Earth. It is estimated on the grounds of the methodology established by ISO 14040: 2006, Life Cycle Assessment: Principles and Framework and ISO 14044: 2006, Life Cycle Assessment: requirements and guidelines, and Publicly Available Specification (PAS 2050) [4].

Although LCA calculates the environmental impact of products or processes along its entire life cycle, it can also be used to assess only one specific stage of that life cycle, as in the present study, where only the operational stage is assessed. The functional unit is one cubic meter of drinking water produced (1 m³), with the quality currently delivered [4].

Two main kinds of data were used: (a) site specific data, collected from internal reports and personal interviews, and (b) data from databases included in or compatible with the used software.

The application of the methodology of the carbon footprint to water treatment processes should include the following key features [4]:

1. A clear definition for purpose of the study, of the use of the product and of the functional unit, which is composed of three parameters: amplitude (i.e. water quantity), the estimated duration of service and the expected quality level;
2. An analysis of the life cycle of the considered product, with a detailed definition of all the involved processes, is necessary to detect all direct and indirect emissions sources. The standard is explicit about this issue: An inventory consists of service, material and energy flows that become the product, make the product, and carry the product through its life cycle. These are defined as attributable processes [5]. They may be listed as follows:
   - capital goods (e.g., machinery, trucks, infrastructures);
   - overhead operations (e.g., facility lighting, air conditioning);
   - corporate activities and services (e.g., research and development, administrative functions, company sales and marketing);

\[
\text{kgCO}_2 = \text{Direct Emissions Data} \times \text{GWP} \left[ \begin{array}{c} \text{kgCO}_2 \\ \text{kgGHG} \end{array} \right] + \text{Activity Data} \times \text{Emission Factor} \left[ \begin{array}{c} \text{kgGHG} \\ \text{unit of measure} \end{array} \right]
\]

\[
\text{kgCO}_2 = \text{GWP} \left[ \begin{array}{c} \text{kgCO}_2 \\ \text{kgGHG} \end{array} \right] + \text{Emission Factor} \left[ \begin{array}{c} \text{kgGHG} \\ \text{unit of measure} \end{array} \right]
\]

\[
\frac{\text{Total CO}_2}{\text{unit of analysis}} = \frac{\text{CO}_2 \text{ Emissions (Biogenic)}}{\text{reference flow}} - \frac{\text{CO}_2 \text{ Removals (Biogenic)}}{\text{reference flow}} + \frac{\text{CO}_2 \text{ Emissions (Non-Biogenic)}}{\text{reference flow}} - \frac{\text{CO}_2 \text{ Removals (Non-Biogenic)}}{\text{reference flow}} + \frac{\text{CO}_2 \text{ Land Use Change Impact}}{\text{reference flow}}
\]

Results and discussions

Energy consumption for drinking water production at WTP Bacau. Energy is usually required for extracting raw water from either source. Some water sources need very little treatment, so their energy intensity is low as is the case of WTP Bacau. Groundwater extraction requires approximately 30% more electricity on a unit basis than surface water extraction. Different factors such as the distance from the water source to the consumer, water abundance, initial quality, and required treatment for use determine the overall energy expenditure per volume unit of water [6-10].

WTP Bacau consumed an amount of electricity, which in 2015 was equal to 239.94 MW h/y (table 1). The connection of equipment from the WTP Bacau at the electrical power supply is made at town network. In the urban water cycle, water supply, transportation, treatment and disposal are services that consume a considerable amount of energy. In this stage electricity is the main energy source. In addition, there is an indirect energy use for the production of chemicals.
The embodied energy associated with raw water extraction is unique to every water system, ranging from the low energy requirements of an unfiltered gravity-fed system to the high energy requirements of a pumped seawater reverse osmosis system.

As can be seen (fig. 1), in the case of WTP Bacau in water treatment process the highest energy consumption per year is registered by the Technical Building which is 40% from total energy consumption and includes Circulation Pump 1, Circulation Pump 2, Laboratory Equipment, pH&Conductivity Meter Water Analyzer Group 1 and 2, Chlorine Contact Tank Sample Water Selenoid Valve etc.

Chemical consumption for drinking water production at WTP Bacau

The production of drinking water from fresh surface water involves several processes, energy consumption and chemical dosing, all having global environmental impacts.

### Table 1

| Chemical Consumption WTP Bacau | Unit cost, EUR/kg | Average effective flow, m³/day | Guaranteed chemical dose, kg/m³ | Guaranteed unit chemical cost, EUR/m³ | Guaranteed annual chemical cost, EUR/y |
|--------------------------------|------------------|-------------------------------|---------------------------------|--------------------------------------|---------------------------------------|
| Raw water NTU 1 - 10           |                  |                               |                                 |                                      |                                       |
| Alum                           | 0.15             | 30,000                        | 0.04                            | 0.0064                               | 70,080                                |
| Lime                           | 0.08             | 30,000                        | 0.02                            | 0.0015                               | 17,510                                |
| PAC                            | 1.25             | 30,000                        |                                  |                                      |                                       |
| Polymer                        | 3.5              | 16,800                        | 0.00015                         | 0.000525                             | 5,748.75                              |
| Cl₂                            | 0.28             | 30,000                        | 0.0015                           | 0.00042                              | 4,599                                 |
| Raw water NTU 10 - 20          |                  |                               |                                 |                                      |                                       |
| Alum                           | 0.15             | 21,000                        | 0.04                            | 0.0064                               | 49,056                                |
| Lime                           | 0.08             | 21,000                        | 0.02                            | 0.0016                               | 12,264                                |
| PAC                            | 1.25             | 21,000                        |                                  |                                      |                                       |
| Polymer                        | 3.5              | 21,000                        | 0.00015                         | 0.000325                             | 4,024.13                              |
| Cl₂                            | 0.28             | 21,000                        | 0.0015                           | 0.00042                              | 3,219.3                               |
| Raw water NTU 20 - 70          |                  |                               |                                 |                                      |                                       |
| Alum                           | 0.16             | 9,000                         | 0.03                            | 0.008                                | 26,280                                |
| Lime                           | 0.08             | 9,000                         | 0.03                            | 0.0024                               | 7,884                                 |
| PAC                            | 1.25             | 9,000                         | 0.01                            | 0.0123                               | 41,062.3                              |
| Polymer                        | 3.5              | 9,000                         | 0.0002                          | 0.0007                               | 2,299.5                               |
| Cl₂                            | 0.28             | 9,000                         | 0.0015                           | 0.00042                              | 1,379.7                               |
| NaOH                           | 0.22             | 9,000                         |                                  |                                      | 500                                   |
| Total                          |                  |                               |                                 |                                      | 245,916.88                            |
chemicals used in water treatment (fig. 2) at WTP Bacau is relative and depends on raw water turbidity (minimum 5 NTU), for example during the winter period raw water is very clean in viewpoint of physico-chemical characteristics and requires only a simple chlorination.

### Chemicals consumption 2015 WTP Bacau t/y

- **Cl**
- **Al2(SO4)3**
- **Polymer (type POUREX)**

**Fig 2. Chemical consumption for water treatment process Bacau**

Energy consumption for drinking water production at SMAT Turin

According to data released by SMAT, power consumption for plant services account for 1.1% of the global. Such figure can be compared with the amount of water taken up, according to the Declaration Annual volumes of derivatives from Surface Waters published by Smart in 2016. The collected data are summarized to provide an overview in table 3 [11].

The calculation of the electricity used (fig.3) is simplified by the presence of such a work, an energy meter arranged by the company responsible for the supply.

**Table 3**

| Operation         | Energy consumption [kWh/year] | Energy consumption MWh/year |
|-------------------|--------------------------------|-----------------------------|
| **Po1**           |                                |                             |
| Clarification     | 128,617.17                     | 12,861.71                   |
| Filtration        | 36,497.00                      | 3,649.5                     |
| Second lifting    | 2,350,080.00                   | 235,008                     |
| Drain sludge      | 198,000.00                     | 19,800                      |
| Total             | 2,713,192.17                   | 271,319.21                  |
| **Po2**           |                                |                             |
| Clarification     | 128,617.17                     | 12,861.71                   |
| Filtration        | 29,568.00                      | 2,956.8                     |
| Second lifting    | 2,348,597.00                   | 234,859.7                   |
| Drain sludge      | 198,000.00                     | 19,800                      |
| Total             | 2,704,782.17                   | 270,478.21                  |
| **Po3**           |                                |                             |
| Oxidation         | 1,422,284.00                   | 142,428.4                   |
| Clarification     | 765,495.60                     | 76,549.6                    |
| Filtration        | 239,987.50                     | 23,998.75                   |
| Second lifting    | 9,258,635.63                   | 925,863.56                  |
| Drain sludge      | 575,240.00                     | 57,524                      |
| Total             | 12,293,642.73                  | 1,229,364.2                 |
| **Total Po1-Po2** | 5,417,974.34                   | 541,797.4                   |
| Total plant Po    | 22,354,549.21                  | 2,235,454.9                 |
| Total bill        | 18,410,525.00                  | 1,813,163.6                 |
| Percentage difference | 22%                      | 23%                        |

**Fig 3. Energy consumption for water treatment Po1-2-3 SMAT Turin**

As we cant observe in table 4 the energy consumption is divided in 5 parts and consists essentially in: extraction of raw water, accumulation and lifting, potabilization, distribution, services. The biggest part is consumed in proces extraction of raw water and it’s approximately 54.9% from the total quantity.

Chemical consumption for drinking water production at SMAT Turin

Already in the 90 SMAT he had embarked on a program to reduce the use of chemical reagents (table 5) used in water purification through the optimization of processes (for example by automatic controls kind of ‘feedback’ and ‘feed-forward) and the adoption of environmentally friendly technologies (activated carbon, Organic, ultraviolet rays, etc.). Thanks to these improvement activities it can be stated that the use of chemicals in the treatment of water intended for human consumption has been optimized at the lowest extent possible consistent with the need to ensure the sanitary quality of the water produced [11].

It should also be remembered that variations in the consumption of some reagents (fig.4), also up to 10–20%, can be considered physiological because conditioned by climatic events that have occurred during this reporting period; For example, heavy rainfall may also require increases up to 4-5 times the average dose the flocculant used (aluminum polychloride) [12].

| Energy consumption % | 2011 | 2012 | 2013 | 2014 | 2015 |
|----------------------|------|------|------|------|------|
| Extraction of raw water | 49.9 | 55.4 | 54.9 | 55.8 | 52.8 |
| Accumulation and lifting | 41.0 | 36.5 | 36.5 | 35.4 | 37.5 |
| Potabilization       | 6.9  | 6.0  | 5.9  | 6.4  | 6.9  |
| Distribution         | 1.1  | 1.2  | 1.2  | 1.0  | 1.7  |
| Services             | 1.1  | 0.9  | 1.5  | 1.4  | 1.1  |

**Table 4**

| Energy consumption for water treatment process - WTP SMAT |
Conclusions

The traditional tool of evaluation of water treatment plants in terms of efficiency in removal of critical parameters and of cost for operative activities must be today integrated with a verification of total compatibility of the operation [14]; in account of the large effect of this aspect; in particular the capacity to generate GHG from energy use and from chemicals transport and utilization must be carefully considered.

The main objective of this paper was to compare the environmental impacts between two water treatment plant one from Romania and one from Italy by using carbon footprint methodology (CF) from a practical and applicability point of view in order to support various water management stakeholders and especially the water treatment operators.

For this purpose, this study has been developed around a tow case studies (Bacau and Turin) to enable comparison of water treatment processes, the amount of chemical and energy used for water treatment processes. The two water treatment plants present rather different approaches to environmental impact definition and quantification due to water treatment process as it was presented in the overview of WTP.

Although the two water treatment plants have different principles for environmental impact quantification, the results have shown differences regarding de energy consumption and quantity of chemical consumption because of the fact that two water treatment plants are very different in point of view of flow rate, number of inhabitants, source of water and we must consider that the source of water in Turin, Po river is affected by industrial pollution while in Bacau source of water Poiana Uzului Lake is not affected by industrial pollution but another aspect that I must specify is the difference between water treatment schemes.

However, the analysis of results has demonstrated the weak and strong points of each water treatment plant and has emphasized the necessity for improving the weak points. For example in the case of WTP Bacau the quality of water which reaches the consumer undergoes changes because of outdated water supply system, in this case measures to be taken refers to renovation of distribution network, operation witch started from last year. Furthermore, the result analysis and discussion pointed out that at least for two stakeholders involved in water management (water operator and management authority).

Concerning the priorities of the Romanian and European research programs, the environmental problems, the sustainable management of natural resources and carbon footprints as an environmental objective in addition to the economic efficiencies when identifying the optimal water supply expansion strategies subject to technical, managerial, and social remain key issues for Romania’s development [15].

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