PROBLEMY EKOROZWOJU – PROBLEMS OF SUSTAINABLE DEVELOPMENT
2014, vol. 9, no 2, 121-130

Drinking Water Consumption in Cracow – an Assessment from a Sustainable Development Perspective

Konsumpcja wody pitnej w Krakowie – próba oceny z perspektywy zrównoważonego rozwoju

Tomasz Stypka, Katarzyna Berbeka

Cracow University of Technology, Institute of Thermal Engineering and Air Protection
ul. Warszawska 24, 31-155 Krakow, Poland
E-mail: stypka@gmail.com

Abstract

The article assesses, from a sustainable development perspective, the current consumption model for drinking water in Krakow. Based on the available literature, it evaluates the quality of tap water in Krakow and compares it with the standards for bottled water. Next it assesses the economic consequences for the average city resident who decides to drink bottled water. The total energy demand for the production, distribution and consumption of bottled water is estimated and is compared to the household energy consumption.

The environmental impact for the current water consumption model in Krakow is estimated by summing the waste reaching landfills, energy consumption, carbon dioxide emission, and Eco-Indicator 99 H/A points. These estimates were calculated based on the data in the reviewed literature revised for the actual quantities of consumed bottled water and bottle recycling levels in Krakow. The potential environmental savings for the city related to an annual reduction of 1 litre of bottled water consumed by an average resident by is also calculated. The different water consumption scenarios are assessed using the multi-criteria Analytic Hierarchy Process (AHP) to see how compliant they are with sustainable development.

Key words: Krakow, sustainable development indicators, LCA, bottled water, PET, AHP

Streszczenie

Artykuł szacuje, z punktu widzenia zrównoważonego rozwoju, aktualny model konsumpcji wody w Krakowie. Na podstawie literatury, ocenia jakość wody wodociągowej w Krakowie, którą porównuje z wymaganiami stawianymi wodzie butelkowanej. Następnie, ocenia efekty ekonomiczne dla przeciętnego mieszkańca miasta decydującego się pić wodę butelkową. Oszacowano energochłonność produkcji, transportu i konsumpcji wody butelkowanej oraz oceniono skalę tej energochłonności w porównaniu z ilością energii zużywanej w gospodarstwach domowych.

Efekty ekologiczne aktualnego modelu konsumpcji wody w Krakowie oszacowano licząc strumień trafiających na składowisko odpadów, energochłonność skumulowaną, emisję dwutlenku węgla, punkty Eco-indykator99 H/A. Szacunki te zrobiono na podstawie danych literaturowych adaptowanych do aktualnych ilości konsumowanej w Krakowie wody butelkowanej oraz przyjmując aktualne poziomy recyklingu butelek. Oszacowano również efekty środowiskowe dla miasta ze zmniejszenia konsumpcji wody butelkowanej o jeden litr przez przeciętnego mieszkańca. Przedstawiono również próbę całościowego zmierzenia za pomocą analizy wielokryterialnej Analitycznego Procesu Hierarchicznego (AHP) jak bardzo poszczególne scenariusze konsumpcji wody są zgodne z koncepcją zrównoważonego rozwoju.

Słowa kluczowe: Kraków, wskaźniki zrównoważonego rozwoju, LCA, woda butelkowana, PET, AHP

Introduction

The healthy lifestyle trends and the lack of trust in the quality of tap water result in mass consumption of bottled water. The problem is particularly significant in rich cities which are visited by large numbers of tourists and also in academic cities populated by young people who are trend setters. Such a behaviour also has consequences from the sustainable development perspective. The most frequently quoted definition of sustainable development *is the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs* (WCED, 1987).

As far as the guarantee of permanent access to clean and healthy water can be regarded as a basic human need, access to bottled water seems to surpass this basic need. The concept of sustainable development can be considered on three levels: ecological, social and economic. However, a problem arises with how to measure sustainable development for such an activity when the negative effects on an economic and ecological level are partially compensated for on a social level. Russell suggests that energy-intensity and material-intensity of comparable products or processes serve as sustainability indicators (Russell, 2010). Life-cycle assessment (LCA) is a tool which enables an assessment of material and energy intensity of tap and bottled water preparation as well as an assessment of the impact on an ecological level. This article attempts to quantify how much bottled water is drunk in Krakow and then using American and Swiss LCA analysis assess the actual environmental costs of such consumption for the city and its residents. Thanks to LCA it is also possible to estimate how the environment and economy will change if an average resident reduces his consumption of bottled water by 1 litre annually. A total assessment method is also presented from the perspective of sustainable development for each of the water consumption scenarios. For the total assessment the multi-criteria Analytical Hierarchy Process (AHP) was used.

The existing water treatment systems are evaluated from an economic perspective as well as from an LCA one (Barrios, 2008). The potential effect of various technological changes on existing facilities are also analysed (Lundie, 2004). General models for the entire water supply and sewerage industry are also being built which can be optimised as they benefit from operational research techniques (Lim, 2010). The article attempts to analyse for a specific city, Krakow a system where the source of drinking water is simultaneously tap and bottled water. The basic problem with this type of analysis is establishing whether the quality of tap water is comparable with that of bottled water, i.e. whether tap water is suitable for drinking directly or whether it has to be boiled first.

An assessment of the quality of drinking water in Krakow

Throughout its modern history, Krakow has been supplied with tap water since 1901. Initially the water was abstracted from the River Wisła but after World War II, due to increased demand and water pollution, additional water abstraction intakes were built on the Rudawa, Dłubnia and Raba rivers. Up to the middle of the 1980's demand for water grew which the supply system could not meet both in quantity and in the quality of water. It is estimated that during this period the supply system supplied only 80% of the required water. The commissioning of a new water abstraction intake *Raba 2* in 1987 radically improved the situation. Political changes in the 1990's reduced the demand for water speeded up the improvement process. However, for the residents, memories of bad quality tap water remain to the present day.

The 1998 Council Directive 98/83/EC is the basic document relating to the quality of water intended for human consumption which defines the standards for the quality of water intended for human consumption. The Directive defines the chemical, physical and biological standards for water in the water supply network. The Polish Health Minister's directive dated 20th April 2010, amending the previous directive dated 29th March 2007, relating to the quality of water intended for human consumption, aligns Polish legislation with that of the European Union. On MPWiK S.A.'s (Municipal Water Supply and Sewerage Company) website there is a statement guaranteeing the good quality of treated water flowing into the municipal network. Values for a number of selected water quality parameters for the last 2 weeks are published (MPWiK, 2013). The MPWiK S.A. Central Laboratory in Krakow currently tests for 140 physicochemical, bacteriological and hydrobiological parameters in raw water abstracted from boreholes, drinking water supplied to the network as well as the water within this network. Since the water supplied to the residents of Krakow easily exceeds the high Polish and European standards, it can be assumed that according to the definition in Directive 98/83/EEC, the water is *clean and healthy*.

A wide scale inspection by the Supreme Chamber of Control (NIK – Naczelna Izba Kontroli) of all water companies in Poland showed that MPWiK S.A. in Krakow is one of five companies supplying the highest quality of water in Poland (MPWiK, 2013).

The water supply network can be a source of secondary water pollution. This hazard is constantly being minimised by replacing steel pipes with plastic ones. It reduces the risk of cloudiness, colouring, iron compounds and bacteriological contamination in water. At the same time the age of the water pipework is being lowered. Due to these actions the number of distribution network failures in the period 2003-2006 was reduced by 27% (Olko, 2008), which affects the quality of water for the customers.

The good quality of water received by customers is confirmed by results from the laboratory tests performed regularly by MPWiK, inspections by NIK, Chief Sanitary Inspectorate (Główny Inspektorat Sanitarny), Sanepid's tests, and tests carried out in 2011 by *Brita* – a manufacturer of water filter jugs (Sanepid, 2011), (GIS, 2011). Summarising the results, Brita stated: *The results for the individual parameters for water in Krakow are relatively low with respect to the norm, which means complete safety in its use. Therefore assessing the suitability of tap water in Krakow for drinking, based on parameters included in the Health Minister's directive, it should be accepted that the water fulfills all sanitary requirements and is of good quality, chemical and microbiological purity* (Brita, 2012).

These facts do not change the consumer's distrusting attitude. In 2009 a survey was carried out by the Public Opinion Research Centre to determine the Polish people's attitude towards tap water. It turned out that 49% of Poles would not drink unboiled tap water, 57% buy bottled mineral water and 11% use filter systems. However, almost everybody complained about so-called *hard water* (E-instalacje, 2012).

In 2011 Brita carried out tests throughout Poland which highlighted that *as many as 61% of Polish people are distrustful of tap water and the reservations they have are mainly related to its quality* (Brita, 2012).

An Assessment of bottled water quality

Being distrustful of tap water, the residents of Krakow turn to bottled water. Its quality is regulated by the Health Minister's Regulation dated 31st March 2011 in the matter of natural mineral water, spring water and table water (*Journal of Laws*, no 85, item 466). This regulation implements both the Commission's Directive 2003/40/EC dated 16th May 2003 as well as the European Parliament's and Council's Directive 2009/54/EC dated 18th June 2009 on the abstraction and marketing of natural mineral waters. This regulation introduced a significant change related to the term *natural mineral water* replacing a long-standing definition (Błońska, 2010). Previously *natural mineral water* implied water containing mineral riches important for human health which was intended to be drunk for dietary, nutritional, revitalising and prophylactic health reasons (Latour, 2010). The new binding definition of *natural mineral water* introduces a significant change and currently any underground water fulfilling certain conditions of primary purity, when bottled, can be called *natural mineral water*. However, only some of them may have a beneficial effect on health. In practice it means that in many waters which can be called *natural mineral water* there are no minerals, or only in very small, trace amounts which has no physiological meaning. Already several waters containing insignificant quantities of minerals, described to date as *natural spring water* have been recently renamed *natural mineral water* (Goczał, 2010).

Economic consequences for the present water consumption model

An average Pole drinks 72.4 litres of bottled mineral water annually (GUS, 2012). Since most people who drink bottled water have a secondary or university education and reside in cities (Piński, 2006), it can be assumed that a resident in Krakow annually drinks 80 litres of bottled water.

A survey of water prices carried out in one of the supermarkets in Krakow showed that there is a wide range of choice both with respect to price and product. There were 177 different types of water in various packaging. Water in the cheapest packaging cost 0.99 zloty (0,25 euro, 1 euro = 4,2 zloty) and the most expensive 27.90 zloty (6,6 euro). The price of 1 litre of water ranged from 0.66 zloty (0.15 euro) to 30.27 zloty (7,20 euro). The mean price of water was 5.34 zloty (1,27 euro) with the median being 2.98 zloty per litre (0,7 euro, Alma 24, 2013). The price of 1 litre of tap water in Krakow is 0.00343 zloty (less than one eurocent, MPWiK, 2012). Assuming that cheap waters are mainly sold and that the average price of bottled water is 2.50 zloty for a 1.5 litre bottle, (1.67 zloty/litre), it means that bottled water is about 500 times more expensive than tap water. Considering that a person should drink 1.5 litres of water daily, a resident of Krakow drinks approximately 548 litres of water annually, of which bottled water amounts to at least 80 litres (15%). Consequently, a resident of Krakow pays between 53 zloty (12,60 euro) and 2,422 zloty annually for bottled water whilst the remaining 85% of water drunk costs just 1.60 zloty.

The effect of bottled water consumption on the natural environment

One of the main burdens on the natural environment associated with the consumption of bottled water is its energy-intensity and the waste produced. Currently 95% of the bottled water sold in the USA and over 90% in Poland is in bottles manufactured from polyethylene terephthalate (PET) (Berbeka, 2012). PET is the most common plastic used in food packaging. It is harder and more enduring than nylon and can be formed and shaped as required. It is resistant to heat, mineral oils, solvents and acids. It is carbonation resistant, strong, light, impact resistant, naturally transparent and fully recyclable. In addition it practically leaves no taste or smell on the products it comes into contact with. The properties of materials used for food packaging are strictly controlled in the EU by framework Directive 1935/2004 (EU, 2004) amongst others. On the one hand, PET is considered to be a safe material for packaging water but studies are indicating that there are various substances, often in significant quantities, found in the water bottled in containers manufactured from PET (Bach, 2012; (Sax, 2010).

Energy is required for PET and bottle manufacture, water treatment, transportation of bottled water, chilling the water and maintaining it at low temperature. The energy demand for bottle production depends on bottle size. For a 1 litre bottle weighing 38 grams about 4 MJ of energy is required (Berbeka, 2012). The energy required for the treatment of drinking water depends on the technology and the degree of pollution. For example ultraviolet disinfection requires only 10 kWh/million litres but the energy required for reverse osmosis can reach up to 1600 kWh/million litres or more as in the case of sea water desalination (Gleick, 2011). Water treatment in a water bottling plant consists of a number of processes.

The transportation's energy demand depends on two factors: distance and means of transport. The vehicles used in Poland have a medium energy demand between 3.5-6.8 J/(kg km) (Gleick, 2011). Table 1 shows the total estimated energy demand for bottled water (Berbeka, 2012).

Table 1. Total energy demand for the production and consumption of one litre of bottled water

Stage	Energy Demand MJ_{th}	Percentage
Manufacture of plastic PET bottle	4	39-71%
Water treatment	0.0001-0.02	0-0.3%
Bottling and labeling	0.01	0-0.1%
Transport – dependent on distance and type	1.4-5.8	25-57%
Chilling	0.2-0.4	3-9%
Total	5.6-10.2	100%

In the above analysis the energy requirements for the long-distance transportation of water through the pipeline or from deep boreholes have not been taken into account. It is assumed that water is first treated and then poured into plastic PET bottles, capped, labeled and packed in a bottling plant. Then it is distributed into shops and chilled before consumption. Based on these assumptions the total energy required for bottled water varies between 5.6 and 10.2 MJ/litre. For comparison, tap water requires on average 0.005 MJ/litre (Gleick, 2009) for treatment and distribution. This means consumption of bottled water is between one and two thousand times more energy intensive compared to that of tap water.

Waste

It is estimated that between 100,000 and 150,000 tonnes of PET packaging is manufactured annually (Berbeka, 2012). Some of it is recycled, but most ends up in a landfill. According to the estimates of Organizacja Odzysku REKOPOL (Warszawa) (Rekopol Recovery Organisation S.A. Warsaw) currently about 40,000 tonnes of PET waste is collected annually (Rokicki, 2005). Other sources estimate that 28% of plastic PET bottles are recycled in Poland (*Onet*, 2012). In 2010, 73% of packaging waste was recycled in some form in Krakow (*Bip Miasto Krakow*, 2010). Based on this data we can assume that the average resident of Krakow, drinking 80 litres of bottled water in 1.5 litre bottles annually, uses 53 bottles of which 39 bottles are recycled whilst the remaining 14 end up in a landfill occupying 0.019 m^3 (density of compressed plastic PET bottles is 44 kg/m^3 (Kreith, 1994) and an average bottle weighs 60 grams). For the whole of Krakow this means 14,000 m^3 of waste being sent to landfill annually.

Adapting LCA analysis for the consumption of bottled water in Krakow

To more accurately assess in the model the effect of drinking water consumption on the environment in Krakow, two reports on a similar subject were studied: a LCA report on drinking water systems in the state of Oregon, USA (Sauer, 2009) and a similar report for the water supply for Swiss regions (Jungbluth, 2006). In the reports various drinking water supply scenarios were analysed ranging from unboiled tap water to bottled water transported long distances. Taken into account were various types of packaging (tap water, bidons, bottles), transportation (different size vehicles, shipping), consumption (boiled, unboiled, chilled) and packaging waste disposal policy. 48 different scenarios were analysed in the American report and 19 in the Swiss report. The American report assesses the effect of individual scenarios measuring their energy requirements, the quantity of waste produced. and 9 categories of impact on the natural environment assessed in accordance with the US Environmental Protection Agency methodology, namely TRACI (Tool for the Reduction and Assessment of the Chemical and other environmental Impacts). In turn, the Swiss report assesses individual water supply scenarios by measuring primary energy use, its effect on global climate change and estimates the Environmental Performance Indicators (EPIs-97 and Eco-indicator 99 H/A). EPI-s-97 is the indicator for measuring energy consumption, the quantity of waste and pollution emissions produced with respect to the Swiss environmental policy objectives. The Eco-indicator 99 H/A is an indicator consolidating individual emission and raw material streams, taking into account their effect on human health and the natural environment from the point of view of an average European. A direct comparison of the results from these two reports and adapting them for the conditions in Krakow is difficult. The reports measure the environmental impact differently. An example of the problem of how to adapt the results in the American report to the conditions in Krakow is the fact that in the state of Oregon 25% of households get their drinking water from private wells which affects the results. In addition, the accepted recycling levels for packaging in some scenarios are difficult to achieve in Krakow. It was eventually decided that the conditions in Krakow were best reflected by the scenarios in the Swiss report. This report envisages nine tap water supply scenarios, out of which four assume water consumed directly from the tap, without chilling or carbonation. The differences between these scenarios are related to the source of the water and consequently to its treatment. The scenarios cover water from abstraction intakes typical for Switzerland (Kr.1), Europe (Kr.2), Swiss rural areas (Kr.3) and Swiss urban areas (Kr.4). The Kr.4 scenario is 28% more energy intensive than the Kr.1 scenario. This is not much if we take into account that the Kr.6 scenario which assumes additional boiling of water in an electric kettle increases the energy demand by 10,000%. The Kr.4 scenario, which describes the water supply to the region around Zurich, is the closest to that of Krakow. The city of Zurich is supplied with water from Lake Zurich and water is treated in six steps: pre-ozonation, rapid sand filtration, intermediate ozonation, granular active carbon filtration, slow sand filtration and reservoir in the plant (Hammes, 2010). In Krakow each abstraction intake uses different water treatment technology (Olko, 2008). They all have coagulation, sedimentation and disinfection stages. Since surface water is the source for both Zurich and Krakow i.e. water having similar parameters, it can be assumed that the water treatment processes have a similar burden on the natural environment in both cities. As for bottled water the Swiss report assumes 10 scenarios depending on the location where the water is produced (Switzerland, Europe), vehicle transportation distance (from 50 to 1000 km), the distribution method to the households (from 0 to 10 km by delivery van), the type of water (carbonated, still), drinking temperature (chilled, not chilled), packaging (1.5 litre PET, 18.9 litre demijohn for recycling, 1 litre glass bottle for recycling). The 3 scenarios for bottled water consumption which were closest to the conditions for Krakow were chosen. All of them relate to consumption from 1.5 litre plastic PET bottles since as much as 90% of bottled water is sold in plastic PET bottles in Poland (Berbeka, 2012). The scenarios differ in the distance the water needs to be transported between the producer and the consumer which according to the report can be 50, 200 or 1000 km. Only one scenario assumed a water transportation distance of 200 km. For Krakow the most popular carbonated and still waters are *Cisowianka, Muszynianka, Nałęczowianka and Żywiec Zdrój* amounting to 73% of the water sold (Berbeka, 2012). Their places of production are Nałęczów (250 km), Muszyna (150 km), Mirosławiec (660 km) and Żywiec (110 km) from Krakow respectively (*Żywiec Zdrój* is bottled in 2 locations) (Grzegrzółka, 2002). Therefore the scenario assuming a transportation distance of 200 km seems the most appropriate. The But.5 scenario assumes that the water consumed is unchilled, carbonated and transported 200 km by lorry. In reality some of the water in Krakow is still and some is sold and drunk chilled. Accepting the assumption that all the water is carbonated and chilled, from the point of view of the burden on the environment, they partially compensate each other and thus the But.5 scenario seems to be a good choice for the water consumption model for Krakow. Based on unit indicators estimated in the Swiss report and assuming that 756,186 residents drink 1.5 litres of water daily, the annual consumption of primary energy and greenhouse gas emissions have been estimated – see Table 2.

Table 2 shows that the environmental impact depends on the water consumption scenario. Many people boil water in the summer only because they are afraid of bacteriological contamination. This causes a hundred-fold increase in primary energy usage. Energy consumption and greenhouse gas emissions are about 400 times greater for a glass of bottled water compared to tap water. This is quite a considerable amount of energy as it is estimated that an average resident uses 780 kWh of electrical energy annually (*GUS*, 2012). This means that primary energy used in water production and consumption comprises from 0.2% to 162% of electricity used in households, depending on the scenario.

In reality water consumption in Krakow is a mixture of scenarios. About 15% of water (80 litres annually) is drunk as bottled water, which approximately corresponds to scenario But.5, whilst the remainder is drunk as tap water which corresponds to scenario Kr.4 or Kr.6. Using scenarios Kr.4 and But.5 as the base the impact of the intermediate scenarios on the environment were estimated. The results are shown in Figure 1.

These charts can be helpful in estimating the expected impacts when changes to the water consumption model are made. The impact of reducing consumption of bottled water by one litre on the global environment and the city was also estimated. These estimates are both city-wide and for one resident. The results are shown in Table 3.

Reducing consumption of bottled water by 1 litre produces primary energy savings of 4.4 MJ which is equivalent to 0.2% of electricity used by each resident. Reducing consumption of bottled water by 1 litre by every resident in Krakow will reduce carbon dioxide emissions by 149 tonnes annually on a city-wide scale and save the residents approximately 1,258,000 zloty annually. Taking into the account the current PET waste recycling level for Krakow a 1 litre reduction in the consumption of bottled water also means a saving of 181 m^3 in landfill. The impact on the environment is measured using Eco-indicator

Table 2. Energy consumption and GHG emissions for different water consumption scenarios for Krakow

Scenario		Unit Indicators		Data for Krakow	
		Energy consumption	Greenhouse gas emissions	Energy consumption	Greenhouse gas emissions
Description	Abbreviation	$\frac{MJ_{eq.}}{l_{water}}$	$\frac{kg\ CO_{2\ eq.}}{l_{water}}$	$\frac{GJ_{eq.}}{year}$	$\frac{kg\ CO_{2\ eq.}}{year}$
Water from a municipal water supply network, unchilled	Kr.4	0.014	4.06E-04	5,631	168
Water from a water supply network, boiled in an electric kettle	Kr.6	1.07	1.65E-02	442,991	6,831
Bottled water, transported 50 km, still, unchilled, plastic PET bottle	But.4	4.35	1.78E-01	1,800,944	73,694
Bottled water, transported 200 km, carbonated, unchilled, plastic PET bottle	But.5	4.38	1.98E-01	1,813,365	81,974
Bottled water, transported 1000 km, still, unchilled, plastic PET bottle	But.9	8.34	4.25E-01	3,452,845	175,954

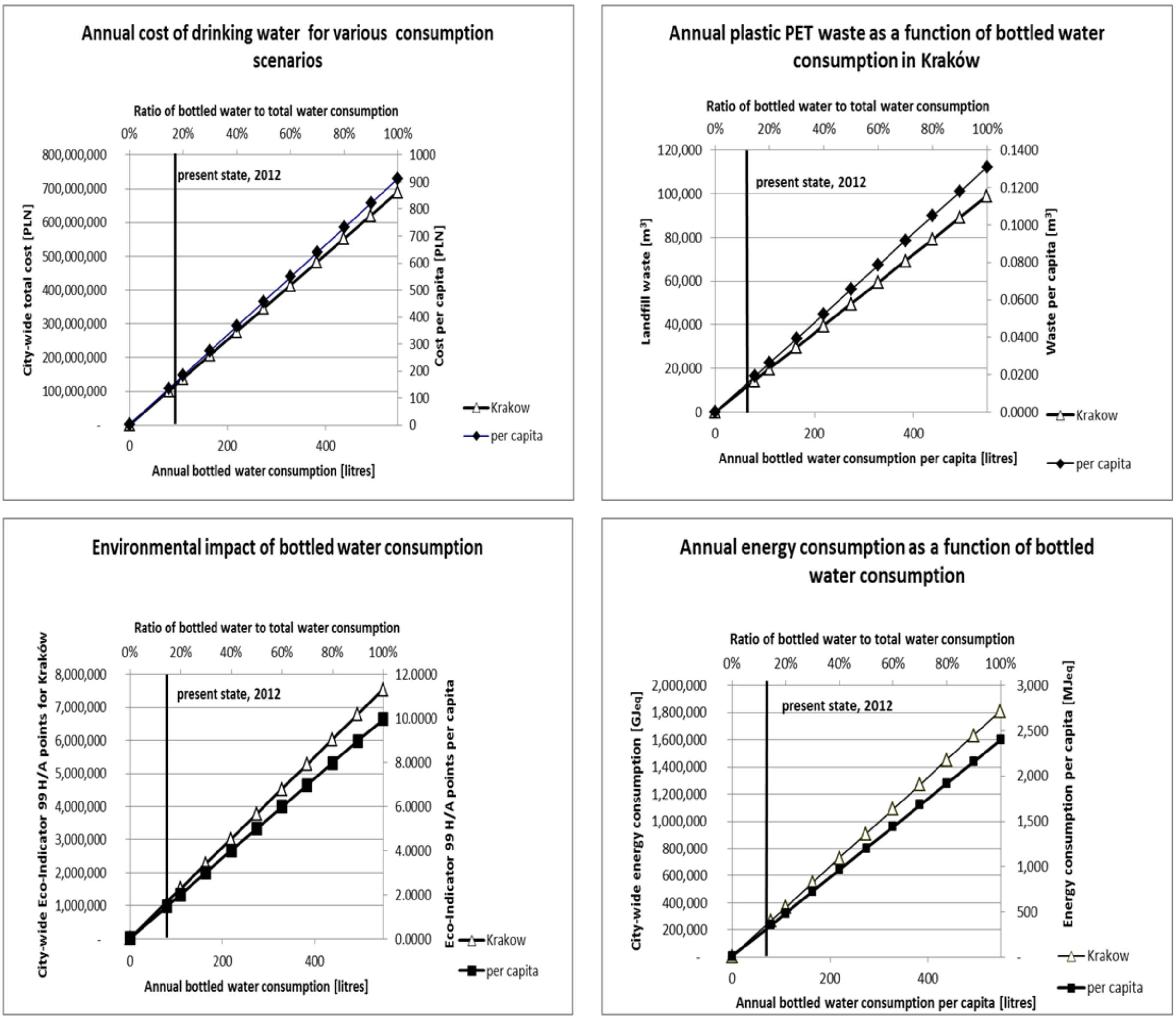

Figure1. Economic and environmental impact for different drinking water consumption scenarios in Krakow.

Table 3 Environmental impact of a one litre reduction in the consumption of bottled water

	Reduction in bottled water consumption	Energy consumption	CO_2 emission	Cost	Volume of waste	Environmental impact
	Litres	MJ_{eq}	kg CO_{2eq}	PLN	m^3	Eco-Indicator99 H/A Points
For 1 resident	1	4.366	0.198	1.66	0.0002	0.0182
For Krakow	756,183	3,301,797	149,417	1,257,711	181	13,733

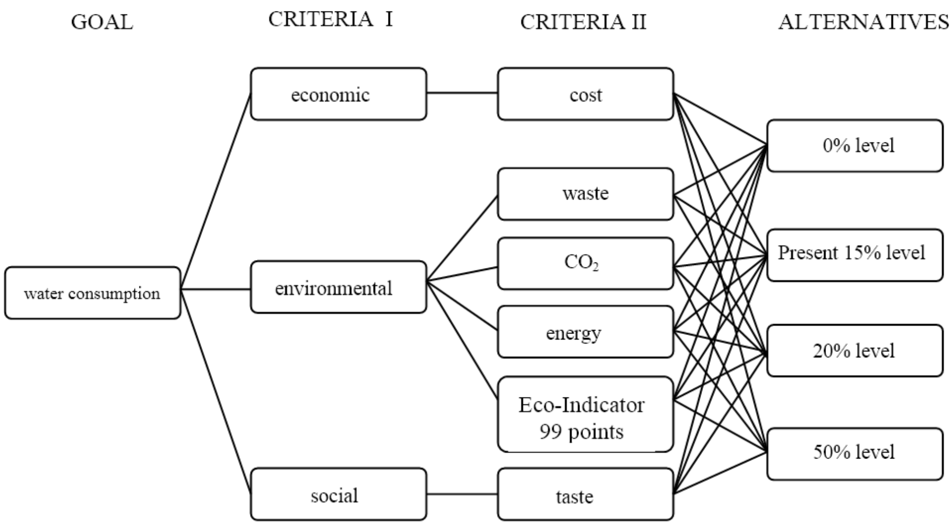

Figure 2. Hierarchical tree of criteria for AHP analysis

99 H/A points. It is estimated that the impact on the environment is $3.93*10^{-5}$ points when consuming 1 litre of tap water. However, for bottled water it is 463 times greater at $1.82*10^{-2}$ points. Eco-indicator 99 H/A points are used primarily to compare different scenarios and 1000 points have been defined as the annual environmental load of an average European citizen. Consequently one can approximate that the reduction of litre in the consumption of bottled water annually by every resident in Krakow is equivalent to a reduction in the environmental load by 14 Europeans. In comparison, for tap water a reduction of 1 litre in the consumption of bottled water is equivalent to a reduction of 463 litres of tap water which is 85% of the annual water consumption intended for drinking purposes.

Evaluation of the water consumption model in Krakow from a sustainable development perspective

The evaluation of individual water consumption models from a sustainable development perspective requires an analysis of these models with consideration to their effect on society, the natural environment and economic impact (Munasinghe, 1993), (Pearce, 1994). The next stage is to work out the individual criteria and to select the comparison method. The Analytic Hierarchy Process (AHP) is one of the universal comparison methods which can be used to compare products or processes from a sustainable development perspective (Stypka, 2012), (ReVelle, 1997). This method involves:

- Constructing a hierarchical tree of criteria,
- Determining the weightings for each criteria using pairwise comparisons,
- Assessing how the analysed solutions fulfill individual criteria by making a series of pairwise comparisons for the solutions. Otherwise assessing the degree of compliance with the criterion by introducing direct data,
- Calculating the final ranking of the individual solutions, which is the sum of the products of the weightings assigned to individual criterion and the degree of compliance for a particular criterion for the analysed solution.

In the case of water consumption in Krakow, four potential scenarios were considered, each differing in the percentage of bottled water of the total water consumed. Scenarios where bottled water constituted 0%, 15%, 20% and 50% of the water drunk were analysed. On the basis of the available criteria, a hierarchical tree of criteria (Figure 2) was constructed and using the described method above the degree of compliance with individual criteria for each scenario was evaluated (Table 4). Minimum and maximum values in each category were assigned to the scenario where bottled water consumption was 0 and 100% respectively. As a social criterion the taste of water was assigned between 0 and 10 points. The same satisfaction level from drinking water was assigned to all scenarios since in reality both professionals and amateurs find it difficult to distinguish the source the water originates from (Berbeka, 2012). The authors of this article assigned the weightings to individual criterion in accordance with the AHP procedure, comparing individual criteria pairwise. The Web-HIPRE application supplied by the Helsinki University of Technology was used for analyses (*Hipre*, 2013).

Table 5 and Figure 3 show the results for the AHP analysis.

In accordance with the accepted procedure the scenario which assumes drinking only unboiled tap water has an overall score of 0.953 where the maximum score is 1. However, the scenario where 50% of wa-

Table 4. Degree of compliance for individual criterion for various water consumption scenarios

Criteria	Unit	Scenarios analysed (% of bottled water consumed)				Minimum	Maximum
		0%	15%	20%	50%		
Energy consumption	MJ eq/capita	7.45	356.00	485.57	1,202.75	7.45	2,398.05
GHG emissions	kg CO_2/capita	0.22	16.03	21.86	54.31	0.22	108.41
Waste	m^3/capita	0.00	0.02	0.03	0.07	0.00	0.13
Cost	PLN/capita	1.88	134.94	184.00	457.19	1.88	912.50
Environmental impact	Eco-Indicator 99 H/A points	0.02	1.47	2.01	4.99	0.02	9.96
Taste	points	5.00	5.00	5.00	5.00	0.00	10.00

Table 5. AHP scores for the drinking water problem in Krakow according to sustainable development criteria

Criteria	Weightings for level ll criteria	Analysed scenarios (% of bottled water consumed)			
		0%	15%	20%	50%
Waste	0.22	1	0.854	0.800	0.500
CO_2 emissions	0.09	1	0.854	0.799	0.500
Energy consumption	0.08	1	0.854	0.800	0.500
Environmental impact	0.62	1	0.854	0.800	0.500
Criteria	Weightings for level I criteria				
Economic	0.250	0.250	0.213	0.200	0.120
Environmental	0.655	0.655	0.559	0.524	0.327
Social	0.095	0.048	0.048	0.048	0.048
Total		0.953	0.820	0.772	0.495

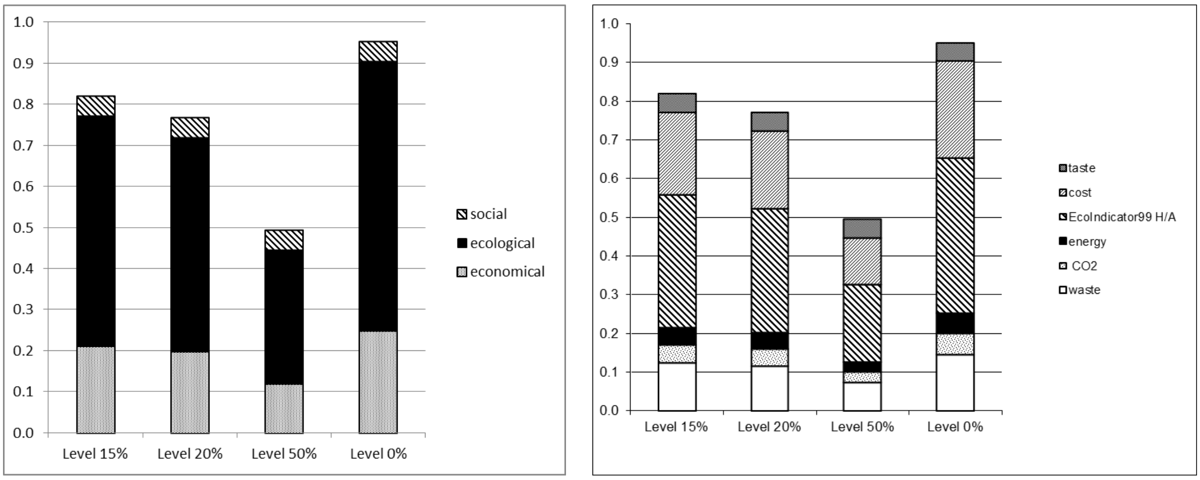

Figure 3 AHP scores for the drinking water problem in Krakow using sustainable development criteria

ter drunk comes from plastic PET bottles scores 0.495. A sensitivity analysis shows that when the weightings are changed the overall score for the individual scenarios also changes, but their relative ranking remains unchanged. The current water consumption scenario for Krakow has an overall score of 0.820 and is 14% worse than the best scenario from the sustainable development perspective. The environmental impact, particularly when measured using Eco-indicator 99 H/A points is the most important criterion for Level I.

Conclusions

An analysis of the water results for Krakow and of the scientific literature on environmental loads for different water intended for human consumption models leads us to the following conclusions:

Tap water in Krakow is *clean and healthy* and is suitable for direct consumption without boiling.

The promotion of drinking tap water is in accordance with the concept of sustainable development, significantly reduces loads on the natural environment, is economically advantageous and does not have negative social impacts.

The average resident in Krakow drinks approximately 547 litres of water annually, of which 80 litres is bottled water. Bottled water accounts for 15% of the total water used for human consumption.

The main environmental burden caused by bottling water is energy demand and waste. The energy demand for bottled water is between 5.6 and 10.2 MJ/litre whilst for tap water it is 0.005 MJ/litre. This means that consumption of bottled water is approximately more than a thousand times more energy demanding than that of tap water. Bottled water is approximately 500 times more expensive than tap water.

Assuming a high level (73%) of recycling of plastic PET bottles, 14,000 m^3 of waste is produced annually in Krakow which reaches landfill following consumption of bottled water.

On the basis of an existing LCA report for Switzerland the current water consumption model for Krakow can be used to estimate the impact on the environment.

According to such estimates, the average resident in Krakow, through drinking water annually, gets through 356 MJ, produces 0.019 m^3 of waste and pays 135 zloty. The environmental load is 1,474 Eco-indicator 99 H/A points.

On a city-wide scale the current water consumption model expends 269,201 GJ of energy and creates 14,473 m^3 of waste. The total drinking water expenditure for the city's residents is 102 million zloty whilst the environmental load is 1,114,896 Eco-indicator 99 H/A points annually. This is equivalent to the total activity of approximately 1,115 Europeans exerting a load on the environment.

Reducing consumption of bottled water by 1 litre annually will save Krakow 3.303 TJ of energy, reduce CO_2 emissions by 149 tonnes, reduce the amount of landfill waste by 181 m^3, save its residents 1.258 million zloty, and reduce the environmental load of 14 Europeans.

The multi-criteria AHP method can be used for the complete evaluation of different water consumption scenarios from a sustainable development perspective. The scenario for drinking only tap water scored 0.953 (on a scale of 0 to 1), whilst the scenario for the actual state of affairs scored 0.820. The evaluation depends on the accepted criteria weightings, but the ranking of the various scenarios is insensitive to changes in weightings.

References

1. *Alma 24*, http://alma24.pl (20.05.2013)
2. BACH C., DAUCHY X., CHAGNON M-C., ETIENNE S., 2012, Chemical migration in drinking water stored in polyethylene terephthalate (PET) bottles: sources of controversy, in: *Water Research* 46, 3, p. 571-583.
3. BARRIOS R., SIEBEL M., HELM A., BOSKLOPPER K., GIJZEN H., 2008, Environmental and financial life cycle impact assessment of drinking water production at Waternet, in: *J. of Cleaner Production* 16, p. 471-476.
4. BERBEKA K., *Analiza możliwości zaopatrzenia studentów i pracowników Politechniki Krakowskiej w wodę pitną,* praca magisterska Politechnika Krakowska, WIS 2012.
5. BIP MIASTO KRAKOW, *Sprawozdanie z realizacji 'Planu Gospodarki Odpadami dla miasta Krakowa – plan na lata 2008-2011 oraz perspektywa na lata 2012-15' za okres od 01.01.2009 do 31.12.2010*, http://www.bip.krakow.pl/?dok_id=21494&lid=90136386&vReg =2&metka=1 (15.04.2013).
6. BŁOŃSKA K., KOZŁOWSKA-WOJCIECHOWSKA M., *Czy wiesz co jesz? Poradnik konsumenta*, Publikat 2010.
7. BRITA, *Wyniki dla Krakowa*, http://www.tester brita-polska.pl/krakowska-woda-z-kranu-spraw dzona, artykul,50, (13.04.2012).
8. E-INSTALACJE, http://www.e-instalacje.pl/a/ 5478,zdrowa-woda-z-kranu (13.04.2012).
9. EU, 2004, *Regulation No 1935/2004 of the European Parliament and of the council of 27 October 2004 on materials intended to come into contact with food and repealing directives 80/590/EEC and 89/109/EEC.*
10. GLEICK P.H., COOLEY H., 2011, *Bottled Water and Energy*, http://link.springer.com/chapter/10.5822/978-1-59726-228-6_8# (21.05.2013).
11. GLEICK P.H., COOLEY H.S., 2009, Energy implications of bottled water, in: *Environmental Research Letters* vol. 4, p.1-6.
12. GŁÓWNY INSPEKTORAT SANITARNY, *Raport o stanie sanitarnym kraju*, Warszawa 2011.
13. GOCZAŁ B., 2010, Lać wodę trzeba umieć, in: *Media i Marketing Polska*.
14. GRZEGRZÓŁKA K., 2002, Źródła pieniędzy, in: *Wprost* nr 20.
15. GUS, *Rocznik statystyczny*, Warszawa 2012.
16. HAMMES F., BERGER C., KOSTER O., EGLI T., 2010, Assessing biological stability of drinking water without disinfectant residuals in a full-scale water supply system, in: *J. of Water Supply: Research and Technology: AQUA*, IWA Publishing 59.10. p.31-39
17. HIPRE, http://www.hipre.hut.fi/ (26.05.2013)
18. JUNGBLUTH N. *Comparison of the Environmental Impact of Drinking Water vs. Bottled Mineral Water,* Uster: ESU services 2006.
19. KREITH K., *Handbook of Solid Waste Management*, McGraw Hill, N. York 1994.
20. LATOUR T., *Uwarunkowania i zakres zmian w terminologii i klasyfikacji wód butelkowanych w Polsce. Źródło. Wody mineralne i napoje*, 2010.

21. LIM S-R., SUH S., KIM J-H., PARK H.S., 2010, Urban water structure optimization to reduce environmental impacts and costs, in: *J. of Environmental Management* 91, p. 630-637.
22. LUNDIE S., PETERS G. M., BEAVIS B.C., 2004, Life cycle assessment for sustainable water system planning, in: *Environ. Science Tech*. 38, p.3465-3473.
23. MPWiK Krakow, http://www.mpwik.krakow.pl/_files/komunikat_Taryfa_2012.pdf (13.04.2012)
24. MPWiK Krakow. http://www.mpwik.krakow.pl/upload/Subpages/komunikat%2015_IV_2013.pdf (20.05.2013)
25. MUNASINGHE M., *Environmental economics and sustainable development*, World Bank, Washington D.C., 1993.
26. OLKO M., *Analiza zmian jakości wody w sieci wodociągowej miasta Krakowa*, Rozprawa doktorska AGH, Krakow 2008.
27. Onet, Butelki PET pod nadzorem, http://biznes.onet.pl/butelki-pet-pod-nadzorem,18490,4957616,prasa-detal (20.11.2012)
28. PEARCE D., *Blueprint 3, Measuring sustainable development*, Earthscan, London, 1994.
29. PIŃSKI J., PIŃSKI A., 2006, Woda z wody, in: *Wprost* Nr 31.
30. REVELLE C., MCGARITY A.E., *Design and operation of civil and environmental engineering systems*, John Wiley & Sons, New York 1997.
31. ROKICKI G., *Sprawozdanie końcowe z wykonania zadania ‘,Zagospodarowanie odpadów poli(tereftalanu etylenu) (PET) pochodzących z butelek po napojach w procesie wytwarzania farb i lakierów’*, Warszawa, Wydział Chemiczny Politechniki Warszawskiej 2005.
32. RUSSELL D., 2010, Uwagi tetryka o zrównoważoności, in: *Problemy Ekorozwoju/ Problems of Sustainable Development* vol. 5, no 1, p.15-22.
33. SANEPID, *Raport o jakości wody do spożycia przez ludzi*, Krakow 2011.
34. SAUER B., SCHIVLEY G., MOLEN A., DETTORE C., KEOLEIAN G., *Life Cycle Assesment of Drinking Water Systems: Bottle Water, Tap Water, and Home/Office Delivery Water,* Franklin Associates, A Division of ERG 2009.
35. SAX L., 2010, Polyethylene terephthalate may yield endocrine disruptors, in: *Environ. Health Perspect*. 118(4), p.445-448.
36. STYPKA T., FLAGA-MARYAŃCZYK A., 2012, Ocena urządzeń energetycznych za pomocą metody wielokryterialnej analizy AHP-hipre z wykorzystaniem kryteriów ekoetykiet, in: *Chłodnictwo,* 1-2.