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# Selected methods of water resources accounting in the aspect of sustainable development

# Wybrane metody bilansowania zasobów wody w świetle koncepcji zrównoważonego rozwoju

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## Abstract

Fresh water is one of the most important natural resources required by the societies' proper operation to meet their biological and industrial needs. Thus, water is a key resource, which availability or scarcity, should be considered carefully in strategies of sustainable social, economic and technical development, with full respect to nature and rules of intergenerational justice. Preservation of fresh water resources for the next generations is highly required by the rule of sustainable development, which results in the need for water accounting for industry and services located in the given watershed as well as for the proper, sustainable water management. This paper contains presentation and analysis of five popular methods used in industrial water accounting i.e. Water Footprint, Life Cycle Assessment, Global Water Tool, Water Sustainability Tools and the exemplary industrial method developed by Schornagel. The apllicational abilities of the described methods and the attempt of the presented methods assessment in compliance to the three main priorities of sustainable development were discussed. The set of basic requirements met by the method orientated towards sustainable development was also presented.

**Key words:** sustainable development, water resources, industrial water demand, waste water, industrial water balance, sustainable water management

## Streszczenie

Słodka woda, poprzez zaspokajanie potrzeb biologicznych i przemysłowych ludzi, stanowi jeden z podstawowych surowców naturalnych niezbędnych do prawidłowego funkcjonowania człowieka. Woda jest więc jednym z kluczowych surowców naturalnych, którego dostępność lub brak powinny być brane pod uwagę w strategiach zrównoważonego rozwoju społecznego, ekonomicznego i technicznego, realizowanego z poszanowaniem natury oraz sprawiedliwości międzypokoleniowej. Zachowanie zasady zrównoważonego rozwoju wymaga zachowania zasobów wody dla przyszłych pokoleń, stąd konieczność dokładnego określenia zapotrzebowania wody na cele produkcyjne i usługowe w danej zlewni oraz zrównoważonego nimi gospodarowania. W pracy niniejszej przedstawiono i omówiono pięć popularnych metod bilansowania zasobów wodnych na cele przemysłowe oraz prowadzenia obliczeń bilansu wodnego przedsiębiorstwa, tj. Water Footprint, Life Cycle Assessment, Global Water Tool, Water Sustainability Tools oraz metodę przemysłową Schornagela. Uwypuklono możliwości aplikacyjne omawianych metod oraz dokonano próby ich oceny w aspekcie trzech podstawowych płaszczyzn zrównoważonego rozwoju. Przedstawiono także podstawowe wymagania jakie powinna spełniać metoda bilansowania zasobów wodnych zorientowana na zrównoważony rozwój.

**Słowa kluczowe:** zrównoważony rozwój, zasoby wody, zużycie wody na cele produkcyjne, ścieki, bilans wodny przedsiębiorstwa, zrównoważona gospodarka wodna

## Introduction

The concept of sustainable development, defined by *Our Common Future* report (WCED, 1987) presents the idea of development not based on the unlimited consumption but guaranteeing the needs of the current generation as well as of the generations to come. The sustainable development is usually considered on three independent but linked areas: environmental (ecological), social and economic (e.g. Harris et al. 2001; Harding, 2006). These three basic pillars of sustainable development may be additionally supported by technical, legal, moral and political aspects (Pawłowski, 2008). Integration of the all mentioned above circles of sustainability allows development of complicated and complex strategies of conscious and directed sustainable development realized with respect to nature and intergenerational justice. Meeting the needs of the current and future generations, indicating ensuring resources, including energy carriers, and intact quality of the natural environment in exploited ecosystems may be achieved by the rational resources and wastes management (partial or total limiting of resources flow together with implementation of resources of lower environmental harmfulness) application of clean and energy efficient technologies of production, use of by-products and recycling of wastes (Kozłowski, 2000). The important contribution in realization of technical and ecological (environmental) aspects of sustainable development is made by the environmental engineering, understood as a science using knowledge of basic science (physics, chemistry, biology) and technical knowledge in preservation, conservation and usage of inner and outer human environment to, inter alia, fresh water supply for domestic and industrial purposes, assuring the proper quality of air, soil and water (surface and groundwater) as well as the proper thermal comfort etc. (e.g. Bhamidimarri and Butler, 1998). Preventing the increasing degradation of the natural environment, resulting in deterioration and pollution of the actually available and possible to use in future water sources is one of the basic research and application tasks for the environmental engineering, because the amount and quality of limited water resources of ecosystems are directly connected to precipitation and surface and underground inflows supplying the basin as well as to discharge of sewages of various origin and anthropogenically modified quality (Palme et al., 2005; Marialokas, 2007; Palme and Tillman, 2008). Thus, we may state that realization of intergenerational justice will depend to the proper management of non-renewable energy carries (Pawłowski, 2010) and to the availability of water of the proper quality required for domestic, municipal and industrial demands.

## 1. Water resources and their usage

Water on Earth, creating the balanced system, is in continuous movement on, above and below surface of the planet, between atmosphere, hydrosphere and lithosphere, known as the water cycle or hydrologic cycle consisting of processes in atmosphere (evaporation, condensation, precipitation and transport), biosphere (transpiration, interception) and lithosphere (infiltration, underground and surface flow, runoff) (Guan and Hubacek, 2008). The graphical statement of water cycle components for selected areas (e.g. river basin), including the distinction between inflows and outflows was presented in Fig. 1. Exploitation of water resources disturbs the natural water cycle in the environment due to direct usage of water in various technological processes, rivers engineering, drainage of wetlands and increased sealing of urbanized catchments surface etc. etc. (Postel et al., 1996; Kestemont et al., 2011). Interferences of the natural water cycle in hydrosphere may also result from phase transitions of water occurring in different industrial processes, e.g. evaporation of water used to cooling.

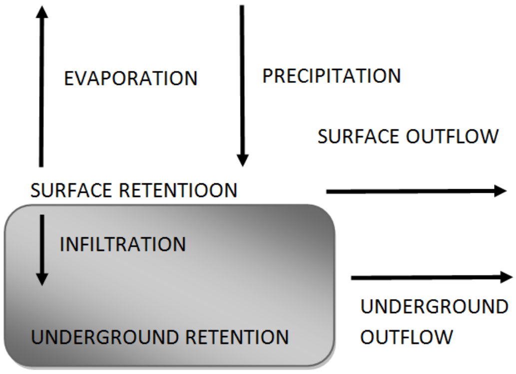

Fig. 1. Components of water cycle in the ecosystems – graphical interpretation of water balance for the hydrologic basin.

Water resources of the Earth equal to approx. 1 385 984 000 km$^3$ (Chełmicki, 2002) seems to be unlimited. However, one should underline that 96.7% of these resources is a saline seawater hold by oceans and seas and containing salinity of between 3.1% and 3.8%. The remaining 3.3% is a fresh water available in various forms: ice sheet, icebergs, glaciers as well as surface water and groundwater. Thus, only about 1% of water on the Earth is a fresh water, available to the direct consumption by humans in domestic, agricultural and industrial activities (Bajkiewicz-Grabowska and Mikulski, 1999). Water is withdrawn from two basic sources: i) surface water in rivers, lakes and retention reservoirs supplied by precipitation and snow melting; ii) groundwater located in void space of aquifers supplied by infiltration (Guan and Hubacek, 2008). The allowable, ready to use, water resources are non-uniformly distributed, it is assumed that the amount of available water in Europe is three times higher than in Africa (Kestemont et al., 2011). In the global scale, the mankind uses about half of the available water resources, from which 70% is used in developing countries for agricultural needs. Considering the natural birth rate in these countries, climate changes, increased production of bio-fuels or minerals mining (including fracturing used during shale gas extraction) the farther increase of water demand may be expected, especially in agricultural and, self-contradictory, highly urbanized areas. The increased water demand and uptake will be followed by discharge of enlarged amount of municipal and industrial sewages to the natural environment. The good example of water stress resulting from the rapid urbanization may be observed in Beijing, China, where the amount of available water per one resident is limited to 300 $m^3$/year (Huang et al., 2012).

Water, despite its renewability and common availability should be treated as the significant and scare natural resource in goods production and services, which shortage in the proper quantity and quality may negatively influence the various economic activities (starting from agriculture to industrial processes) located in the given watershed (Guan and Hubacek, 2008). The excessive water withdrawal from surface sources may result in disadvantageous ecological changes in ecosystem of the stream (deterioration of breeding conditions, degradation of vegetation, disturbance of thermal-oxygen relations) leading to decrease of self-purification capabilities of the stream, which in turn, as a characteristic feedback loop, may cause the decrease of available fresh water of required quality coming from the surface intakes (Chełmicki, 2002). The renewable resources of groundwater, in hydraulic contact with the basin surface and supplied by infiltrating rain or melting water may be easily polluted by the substances hardly absorbed on particles of soil solid phase – e.g. industrial wastewater containing huge amounts of heavy metals or the other toxins. Thus, the amount and quality of available raw surface waters and groundwater is directly connected to water management of human settlements and industrial sites localized in the given basin, volume of local raw water withdrawal for domestic, municipal and industrial purposes, and finally efficiency of local waste water treatment plants. Pollutants migrating together with the untreated or treated improperly wastewater to the ecosystem of the basin spread in streams and aquifers reducing the amount of available raw water of required quality. Additionally, pollutants transported downstream the rivers may negatively affect the water resources located in the lower parts of the basin, reducing also the economic potential and quality of the environment and life of the residents of the involved regions (Guan and Hubacek, 2008). The another threat may be posed by the pollutants migrating from outside the borders of the considered catchment e.g. transported by precipitation.

During investigation of industrial sites localization, exploitation of the natural resources or any business operation requiring fresh water delivery, one should remember that the discussed in this paper, or statistical annals and other media water resources commonly are related to a larger area, e.g. area of the whole country, administrative division or hydrographical units e.g. drainage basins. But in fact, water uptake from surface and underground resources is, on the one hand, practically a spot process (in relation to the area of catchment) and on the other has a significant ecological, economic and social influence on the distant areas from the location of water intake or sewage discharge (Chełmicki, 2002; Schornagel et al., 2012). Particular care should be taken with regard to the analysis of available renewable water resources in cases of technologies characterized by a significant water demand and generating huge amounts of highly polluted and difficult to treat wastewaters. The example of such technology may be, nowadays commonly discussed, the hydraulic fracturing applied to shale gas extraction, in which water, the main component of the fracturing liquid, is used in the amount of 7500 - 19000 $m^3$ (Arthur et al., 2010; EPA, 2010) for fracturing of one horizontal shaft. From 20% to 80% of the fracturing liquid, containing various amendments (polymers, scale and corrosion inhibitors, iron controllers, friction reducers, surfactants, gelling agents, disinfectants, crosslinkers etc.) returns to the surface establishing the potential threat, considerably reduced by the proper reprocessing e.g. secondary usage in fracturing, pollutants treatment or depositing in impermeable soil layers. The well-known extreme historical example of improper accounting and management of water resources combined with mining activities is groundwater pollution in the area of nowadays abandoned city of Picher, Oklahoma, the USA. In the first half of the 20th century Picher was one of the most important zinc and led mining center in the USA. The extensive management, accumulating spoils in spoil tips and pollution of groundwater, infiltrating into unsecured abandoned mining shafts resulted in the fact than population of Picher in 2010 was equal to 10 persons (starting from 9766 in 1920, 5848 in 1950, 3951 in 1960, 2363 in 1970 and finally 1640 in 2000).

Conservation of principles of the sustainable development requires preservation of water resources for the future generations, which in turn leads to necessity of the precise water resources accounting for municipal and industrial requirements in the given basin and their sustainable management.

## 2. Methods of water accounting

Among all known methods of water accounting – beside the traditional industrial method – it is advisable to consider methods presented in the report *Corporate Water Accounting* prepared in 2010 for UNEP (United Nations Environment Programme) (Morrison et al., 2010). The four main modern, proecological and, more or less, orientated towards the sustainable development methods of water resources accounting were presented in the report: Water Footprint, Life Cycle Assessment, WBCSD (World Business Council for Sustainable Development) Global Water Tool and GEMI (Global Environmental Management Initiative) Water Sustainability Tools. There are also the alternative methods, e.g. recently proposed by Schornagel et al. (2012) the generic method of water accounting for industrial sites.

### *2.1. Industrial water resources accounting*

The traditional industrial method of water resources accounting orientated towards meeting the technological requirements and decreasing the water related risks as well as ensuring the financial profits assumes quantitative and qualitative analyses of water uptake, usage (used irrecoverably in production process) and discharge to the natural environment (Schornagel et al., 2012). The effects of quantity and quality of available water for technological purposes and quality of sewage discharged to the wastewater receiver as well as the amounts of water lost are being assessed from a point of view of a company, necessity of the additional water related charges, adjustments of technology and used equipment. The assessments of water account performed in this way consider only the selected environmental and economic issues, thus its application in sustainable development assessment is limited.

### *2.2. Water Footprint*

Water Footprint is a method allowing to determine the total yearly amount of water used in production of goods and services for the precisely defined consumer: a family, settlement, city, region, catchment, country or industrial site. Water Footprint is based on the virtual water concept understood as the volume of water used to production of goods and services on every step of the production in a given time and in a given watershed. This method does not consider the properties of a basin and its condition before water intake and after discharge of the wastewaters. Water resources in Water Footprint method are divided into three independent components, which may be compared singularly or in groups: blue, green and gray water (Hoekstra et al., 2011). The blue water footprint is the volume of water consumed (evaporated or incorporated into the product) to produce the goods or services withdrawn from surface and groundwater resources, the green water footprint is the volume of rainwater consumed during the production also from moisture soil, the gray water footprint is the hypothetical volume of water required to dilute polluted wastewater to such an extent that the quality of the water meets the local water quality standards (Morrison et al., 2010; Schornagel et al., 2012). Thus, the amount of water for production is determined by totally consumed and withdrawn from the ecosystem blue and green waters. This method does not manage directly the amount of water abstracted and withdrawn to the source. The quality of water is defined indirectly, the qualitative characteristics is presented as the virtual indicator – the gray water. Distinguishing the green waters seems to be highly substantial for the users of agricultural ecosystems in which the production capabilities are directly connected to water availability for plants in soils. The comparison of water balance components, especially the available soil retention, presented usually in millimeters of water per given area, to the required green water for the selected cropping may help to improve the cultivation practices, including irrigation. Water Footprint in industrial applications allows analysis of water volume used directly in production in the scale of the company or a selected part of the production process line or even the single production unit. Water Footprint is suggested to be positively rated by the business side as the basic platform for understanding the usage of water in production and services and water related risk assessment, especially in case of the strategic analyses and setting the long-term goals (Morrison et al., 2010). Unfortunately this method does not allow application of the basin properties, water availability and spatial development of water consumer to water related analyses. Additionally, Water Footprint allows no qualitative assessment of influence of the industrial site on the natural environment besides the simplified virtual grey water. The validation of the Water Footprint method from the positions of the sustainable development shows considerable application potential on the environmental area allowing to introduce the amount of production water and, in limited degree and simplified manner, the water quality into environmental analyses. Thus, its wide range of popularity becomes understandable. Unfortunately, environmental analyses performed by this method do not cover the properties of the basin and its condition after wastewater discharge. Application of the Water Footprint in economic field of sustainable development may be helpful in understanding the use and consumption of water in production process. Usage of green water concept allows crops management planning, including irrigation which is a basic procedure in the agricultural water management. The discussed method has no application in the field of social area of sustainable development, because there is no possibility to determine the social influence of studied investment.

### *2.3. Life Cycle Assesment*

Life Cycle Assessment (LCA) is a highly popular tool method allowing the determination of environmental effects of a product or a service during the time duration of product existence – life. Life cycle of the product covers the time period from obtaining raw materials through the each stage of production, distribution and usage, until the utilization of wastes derived from this product. The principles of environmental analyses performed with use of the LCA are given by ISO 14040 and 14044 standards of 2006. According to ISO standards, the LCA analyses are conducted in four separate, but complementary, blocks covering (ISO 14040, 2006; ISO 14044, 2006): determination of goal and scope, inventory analysis, impact assessment and interpretation. Determination of goal and scope covers the definition of analyzed system boundaries and functional measures of a given product or service. Inventory analysis covers determination of input-output data significantly influencing the natural environment; in case of LCA application to water balance analysis it can be: volume of drawn water, spatial localization of its use and consumption, concentrations or loads of pollutants discharged to the environment with wastewaters. The assessment of product life cycle effects covers the conversion of previously defined environmental input-output variables into respective categories of environmental impacts: quality of public health, fresh water resources, global warming etc. etc. Then, the interpretation covers quantification of impacts on environment determined on the previous stage in order to allow conclusions concerning effects of a given product or service on the natural environment. The LCA is being commonly applied in the different branches multi-level analyses (since a singular industrial site, through catchment, administrative region, to the whole countries) of three main groups: engineering decision making concerning technology of production, political regulations of several levels and economic decisions covering environmental charges (Koehler, 2008; Bayart et al., 2010; Morrison et al., 2010).

The analysis of LCA capabilities in environmental level of sustainable development shows numerous possibilities of this method applications resulting from including quantitative and qualitative characteristics of water source, drawing and using of water in the production, impacts of investment on resources and receivers quality etc. etc. This method allows development of environmental impacts assignments of the industrial site practically on the ever step of product life cycle, including also factors unrelated to water management: emission of greenhouse gasses and volatile pollutants. However, LCA does not consider the influence of pollution or draining of the water resources on the natural environment of the basin and the water source is treated in a simplified way, without taking into account its renewability. The applicational abilities of LCA on the economic field of the sustainable development seems to be extraordinary vast. This method allows different, environment related, decision of economic and political character, including e.g. determination of environmental charges. The LCA has also some significant potential in the social field of sustainability. It allows assessment of water related impacts of the company on the social life, public health and life quality of the studied catchment population.

Despite its high popularity, especially in agriculture or food production, the LCA was not completely and comprehensively applied to water accounting (Morrison, 2010). Usually water related issues in LCA were considered as the total volume of water drawn from the environment to produce a given product or service (Morrison, 2010). It results from the lack of the proper precise tools allowing consideration of water source, its renewability, characteristics of water consumption in the process of production and environmental impacts of water draining and its qualitative deterioration in the analyses (Owens, 2001; Koehler, 2008; Schornagel et al., 2012). Therefore, new modifications of the standard LCA procedures allowing better introduction of this method into water resources and consumption accounting appear. Bayart et al. (2010) proposed the method enabling cataloging and assessment of use of water from the retention reservoirs basing on the impacts of the reduced water resources. The analyzed environmental impacts may be recognized and assessed according to the new, proposed by the authors, categories: humans as well as biotic and abiotic factors. Additionally the quantitative water resources may be classified according to the distance between location of water source and place of its consumption, thus, expenditures required for water transport and functionality of water usage for individual users. The next attempt of LCA adaptation to water resources accounting is a method proposed by Mila et al. (2009). The LCA assessment is in this case based on four paths of impact (Mila et al., 2009): i) changes in availability of fresh water affecting the human health, ii) changes in availability of fresh water affecting quality of the ecosystem, iii) groundwater drawing resulting in its deficit, iv) soils usage affecting the water balance and quality of the ecosystem. Therefore, the manners of water stress quantification basing on indicators of evaporative water use in the second path and decrease of water potential of ecosystem in the third path are presented. According to Schornagel (2012) both described modifications to the LCA do not fulfill the requirements of industrial water accounting because the assessment of water resources quality by application of the criterion of distance between water source and water use locations is often impossible (in cases when the used water is not treated to the level of source) and the water withdrawn from the cycle is not a part of a cycle containing components of water intake and evaporative use. However, the both mentioned modifications of LCA clearly expend the possibility of the method application, assessed from the point of view of sustainable development, especially at the environmental level, due to including the impacts of reduced water resources on the environment and effects of changes in water availability on ecosystem. Additionally, the range of LCA application is also increased in the social circle of sustainable development by including to analyses the changes of fresh water availability impacting the quality of life and public health of human population.

### *2.4. WBCSD Global Water Tool*

Global Water Tool is a free, MS Excel based tool, developed by World Business Council for Sustainable Development and allowing companies and organizations to analyze water use and water related risk in connection to enterprise activity, investment or its full supply chain. The above analyses are performed basing on the total water demand, water withdrawn to the environment, information about technical and industrial infrastructure related to the range of basin or administrative unit (Morrison et al. 2010). Application of Global Water Tool allowing information about water balance of the investment by clear, but not directly connected, indicators (e.g. water demand, volume of returned or reused water and volume of discharged wastewaters) and information presenting the relation between the investment and water management and water resources for catchment, region or the whole country. Water Global Tool seems to be a simple, useful tool allowing the identification of dubious, from the point of view of risk management, links of water management of the company (Morrison et al., 2010). Though, this assessment is performed mainly based on geographical data, such as spatial development of the several divisions of the technological chain of the investment, localization of water sources, intake and discharge points. The discussed method works well in cases in which it is necessary to obtain the information concerning the percentage of investment, or any other activity, localization in regions characterized by water stress, the amount of employee affected by water deficit (Morrison et al., 2010), thus, the recognition of territories covered by enterprise activity endangered by water stress of various types. Unfortunately, the Global Water Tool does not allow the rigorous analyses of environmental impacts of the investments because the qualitative issues are defined in a strongly simplified way. The analyzed streams may represent only fresh or polluted water, without any intermediate conditions, types of water use or including the selected indicators of water quality. Taking into account the general description of water streams in water management (water drawn, returned/consumed and discharged), simplified formulation of qualitative issues and lack of possibility to include the effects of water drawing and wastewater discharge to the analyses one should state that accomplishment of full and comprehensive assessment of investment's environmental impact is impossible. Global Water Tool allows the basic, based on risk assessment, connected to water management of the investment economic and political analyses throughout allowing the identification of hotspots in technological and production line of the industrial site endangered by water stress, including the spatial development of the individual stages of production in the analyzed catchment and relation between volume of water drawn for production purposes and the total water demand on the studied basin. Consequently, the main possibility of Global Water Tool on the social field of sustainable development allows assessment of the range of social impacts of the investment, e.g. by determination of the geographical range of water stress caused by the industrial activities and affecting the spatially developed population of the basin. The application of Global Water Tool into full range of sustainable development analyses is limited by the lack of precise quantitative and qualitative assessment on the environmental field which also limits the applicability on economic and social fields (Morrison et al., 2010; Schornagel et al., 2012).

### *2.5. GEMI Water Sustainability Tools*

The next free, accessible by the Internet, collection of tools allowing industrial water accounting is Collecting the Drops: Water Sustainability Tool and Water Sustainability Planner developed by the American non-profit organization GEMI – Global Environment Management Initiative (gemi.org). The Water Sustainability Tool, developed in 2002, allows formulation of water management strategy for the industry, basing on five separated modules covering water use, impact and sources assessment, business risk and opportunity assessment, strategic direction and goals setting and, finally, strategic development and implementation. The presented modules, however, do not allow the quantitative and qualitative analyses of water management of the company but the rater is confronted with the series of questions setting the base for establishing the water strategy for the investment. Water Sustainability Planner, on the other hand, is a tool introducing a user of a given object to the process of water demand assessment related to water availability in the region of the industrial site, impacts of the site on existing water resources and identification of factors endangering the continuity of production. Water Sustainability Planner is consisting of two main modules covering water use by the facility and impact assessment program as well as water management risk assessment. Assessment of facility water use is based on the flow diagram representing water supply and sewage removal for the industrial process or site and performing the calculations of the simple water balance of process/site covering inputs and outputs: total water used, the volume of overall losses in production (evaporation, infiltration, water contained in the product, surface runoff etc. etc.) and wastewater discharged. The above enable the analysis of water supply for the industrial site allowing the assessment of possible improvement of its water use layout by recycling of the selected water streams. Water quality in this method is not determined in quantitative manner but is only presented as fresh water and discharged wastewater which permits the precise environmental impact analyses for the individual stage of production. The risk assessment in water management of the company is a questionnaire providing questions from six independent categories related to operation of the investment and the other users of water in the same area (watershed, reliability of water supply, efficiency of water supply, compliance, economics of water supply and social context) which enable categorization of water related risk for an investment in the scale from 0 to 5. Water Sustainability Tools present the wide approach to problem of company functioning and its presence in the watershed already occupied by the other users of water, however the applied methods of analyses should be treated as simplified, performing of which should be, after collection of required data, available for beginning users (Morrison et al., 2010). The main simplification reducing application of Water Sustainability Tools on the environmental field of the sustainable development is the lacking possibility to include to the analyses the quantifiable indicators of pollution in water discharged to the watershed. Despite the fact that, the Water Sustainability Planner as a tool covering water sources assessment, values of its uses, loss and discharge allows the simplified quantitative assessment of investment impacts on water resources of the basin, the lacking possibility of qualitative assessments significantly decreases the range of potential application of this method to environmental analyses of the sustainable development. The GEMI tools, however, can be successfully applied in economic and social field of the sustainable development. Risk management, strategic management and planning in relation to water resources of the watershed and water management of the industrial site or investment, basing mainly on the outer factors influence analyses are possible in Water Sustainability Tools by GEMI. Additionally, the social context, legalities and presence of the other users of water in the basin, including the analyses of possible interactions between the individual users of water may be introduced to impact assessment performed by these tools.

### *2.6. Alternate methods*

The new method of industrial water accounting, proposed recently by Schornagel et al. (2012) and successfully applied to analysis of water balance for energy production may be the example of the alternate method to the four presented in UNEP Corporate Water Accounting report. This method assumes application of measurable and classifiable intakes, discharges and losses of water in the technological scheme of the industrial site. Water withdrawals in this method are categorized according to their source, volume, quality, location and time, wastewater discharge by volume, quality, location and time, while water consumption (losses) are defined by volume and quality in the context of a given object location in the production line of the company. The streams of withdrawn water may be assigned to six possible sources: sea, surface water, groundwater, collected storm water, municipal water and off-site wastewater. Their quality may be determined by freely selected physical, chemical and biological parameters. Streams of post-production water (wastewater) discharged to the environment are analyzed basing on meeting the requirements of local standards for tested water basin. The water lost during the production process (evaporation, transpiration, part of a product) is handled in similar way. Thereafter, the measurable and categorized individual streams of water withdrawn, discharge and loss are combined into streams describing the properly grouped technological scheme of production (including chain of supply) in regard to a given energy carrier. Thus, the combination of economic aspect of the company functioning, its technological structure, water supply and wastewater removal, the natural environment (source of water and receiver of discharged wastewater) and risk assessment connected to quantity and quality of water and wastewater is possible. The generic method should be rated as complex, allowing to reflect the industrial connections regarding to a selected energy carrier, various elements of production line and supply chain, localized in different, distant parts of watershed or using various technologies, of varied quantitative and qualitative water demands. The mapping of spatial development of technologically diversified elements of the production line allows introduction of legal limitations of water withdrawal from the ecosystem and sewage removal (water intake costs, environmental charges etc. etc.) to the analyses. Additionally, it is possible to analyze the selection of the individual technologies in relation to their water demand and their qualitative requirements in the aspect of the water sources availability, i.e. location, reserves and quality. In order to illustrate the possible technologies and their spatial development values of water streams are presented for the integrated industrial supply chains, as the range values, mean values of which may be applied to the direct comparisons (Schornagel et al., 2012). This method can be easily adjusted and applied to the freely selected technological chain, not only to the energy production. However, the generic methods excludes application of directly used green water (precipitation or melting water retention in soil) in cropping and food production. Additionally, this method focuses basically, at first, at the water management of the industrial site, the impacts of the facility on the natural environment of the catchment is a secondary goal. The quantitative and qualitative impacts assessment is possible but the result would be slightly simplified because the emphasis would be placed on the allowable values of pollutants concentrations determined in the requirements for a given watershed instead of the precise analyses of water quantity and quality. Additionally, the generic method of industrial water accounting, as focused on manufacturing demands, excludes the assessments of sustainable development on the social, and partially on economic field.

The basic capabilities of all discussed industrial water accounting methods on the three main fields of the sustainable development are presented in Tab 1.

## Conclusions

It was demonstrated in this paper that fresh water, withdrawn from surface of groundwater sources, is one of a basic natural resources required to sustainable functioning and development of the population inhabiting the given watershed. Availability of water of proper quality and in required quantity allows the sustainable biological development of mankind, but also of industry, infrastructure, economy, social life etc. etc. together with sustaining the proper level of natural environment. Similarly, the wastewater discharge to natural environment may create a serious threat on the environmental and in the effect, on the social and economic area according to limitation of available fresh water, required to the proper biological and economic functioning of the society. Thus, water is one of main sustainable development indicators in environmental, social and economic field. The awareness of quantitative and qualitative water balance of the industrial site or investment, its impacts on the environment quality and water resources, economy and life of the watershed population as well as the proper water management combined with risk analysis become the pivotal needs in planning the sustainable strategy of company development. The five most popular complex methods of industrial water accounting in relation to natural water resources of the watershed, its infrastructure, social needs, actual standards and requirements, economic aspect of company and society functioning were presented. Unfortunately not all of the presented methods allow the simultaneous analyses of company functioning in aspects of water resources and water management of both industrial site and watershed on all three fields of the sustainable development – ecological, economic and social. Assessing from the point of view of rule of the sustainable development, the most suitable seems to be the Life Cycle Assessment method, especially modified, because it allows, more or less complex, analyses on all the three fields, environmental, economic and social, including characteristics of water sources, quantitatively and qualitatively described water streams used by the investment or discharged to the environment, environmental impacts (including, after modification, impacts of reduced water resources and effects of changed availability of water or even water deficit on ecosystem functioning), quality of life and health of the population. The LCA method may be assumed as the most developed, complete and complex of the all methods discussed in this paper.

Analyses of sustainable development on all the three levels are also possible when Global Water Tools, Water Sustainability Tool and Water Sustainability Planner are applied, however these analyses may be shallow and simplified. Despite the fact that qualitative environmental impacts analyses include geographical and demographic data they are markedly simplified or, in some cases, even impossible (in case of Water Sustainability Planner excluding quantifiable wastewater quality). Additionally, the social analyses are limited to determination of the range of water stress zone in the watershed. The limited applicability seems to be characteristic for the another methods presented in this paper, the Water Footprint and industrial methods, e.g. generic by Schornagel, which exclude the direct conducting of the social analyses. On the other hand, it is advised to remember that the industrial methods are characterized by the significant specificity, accuracy and precision in quantitative and qualitative quantification of water and wastewater streams in water management of the company and the whole watershed, including sources of water and receivers of sewage and possible changes caused by investment functioning into analyses. These methods are also orientated towards the risk assessment and economic aspects of water management. It is clearly visible that to define strategy of the sustainable development for the industry, on environmental, economic and social level, including also political and legal areas, the simultaneous application of several tools may be necessary.

The alternative for the presented situation may be the development of a new, complex and adjusted to the sustainable development method of water management analysis and industrial water accounting allowing:

- Quantitative and qualitative definition of water sources in the catchment, streams or volume of water withdrawn from the ecosystem, used, consumed and discharged after the technological process as wastewater to the environment;
- Inclusion of spatial development of water sources, elements of production chain, localization and range of the investment and position of wastewater receiver;
- Determination of quantitative and qualitative impacts of the investment on the water management in the basin, water sources and quality of wastewater receivers, including their biodiversity, also in the watershed located downstream the river;
- Identification of potential threats and disturbances of the natural quantitative and qualitative water balance of the watershed;

Table 1. The basic characteristics of discussed methods of industrial water accounting.

| | Environmental field | Economic field | Social field |
|---|---|---|---|
| Water Footprint | - Includes the volume of water used for production;<br>- Blue, green and gray water;<br>- Simplified pollution: hypothetic water volume required to dilution of polluted sewage to values allowable by the local requirements;<br>- Wide range of application;<br>- Excludes watershed properties and its condition after wastewater discharge. | - Includes green water helpful in irrigation planning;<br>- Allows simplified analyses – base to understanding of role played by water in production. | - Excludes possibility to determine the social impacts of the investment. |
| Life Cycle Assessment | - Includes volume and location of water source;<br>- Includes environmental impacts of the company;<br>- Wide range of application;<br>- Simplified description of water source and its renewability;<br>- Excludes effects of water source pollution or draining on watershed environment. | - Allows political and economic decision making;<br>- Helpful in calculating the environmental charges. | - Includes impacts of the investment on social life, life and health quality of watershed population. |
| Global Water Tool | - Includes water demand and wastewater discharge to the environment and their location;<br>- Analyses based mainly on geographical data;<br>- Simplified qualitative issues.<br>- Excludes quantitative and qualitative environmental impacts analyses of the investment. | - Allows only political and economic analyses related to range of investments impacts;<br>- Allows water related risk management including the spatial development of production chain. | - Allows only to determine the range of social impacts of the investment (e.g. range of water deficit). |
| Water Sustainability Tool and Water Sustainability Planner | - Includes water withdrawn and water sources assessment, water losses and sewage discharges;<br>- Allows impacts assessment of the investment on the water resources of basin.<br>- Excludes qualitative analyses – no capabilities to quantify the pollutants. | - Allows risk management, strategic management and strategic development planning. | - Includes presence of the other users of water in the watershed, allows interaction between water consumers. |
| Generic industrial method (Schornagel et al., 2012) | - Precisely defined streams of withdrawn water, its sources and wastewater discharges as well production losses.<br>- Freely defined quality of analyzed water streams by optional physical, chemical and biological parameters.<br>- Simplified environmental analyses (compliance to local requirements). | - Allows risk management in water management;<br>- May allow the economic decision making, or concerning the technical infrastructure and affecting the economy of the company. | - Excludes possibility of social analyses. |

- Risk management in water management of the company through selection of hotspots and areas of production chain highly endangered by water stress;
- Strategic planning and economic decision making considering development of the company in relation to its water management and availability of water as a natural resource;
- Determination of range of industrial site impacts on the water management in the watershed;
- Calculation water and environmental charges, identification of reasons and location of streams, processes etc. etc. in the technological line leading to exceeding the allowable by the local requirements concentrations of pollutants in wastewater discharged to the environment;
- Predicting the effects of investment functioning in the given water related conditions on the industrial development of the region, increase of arable areas, decrease of fallow lands etc. etc. directly influencing the economic potential of

the basin and social issues: employment, unemployment, migrations.

- Determination of investment impacts on life quality of population inhabiting the watershed, water availability for municipal demands, quality of water for household, recreation and industrial requirements;
- Predicting the eventual threats for population health consequent on water stress or pollution of water sources;
- Determination of range of water deficit for watershed population caused by the investment functioning, decrease of fresh water availability for household, municipal and industrial purposes of the society.

The method of industrial water accounting meeting the requirements defined above should allow the planning, analyses and inference an environmental, economic and social level according to requirements of the sustainable development.

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