

# Amount of water needed to save 1 m<sup>3</sup> of water: life cycle assessment of a flow regulator

Markus Berger<sup>1</sup> · Michael Söchtig<sup>2</sup> · Christoph Weis<sup>2</sup> · Matthias Finkbeiner<sup>1</sup>

Received: 19 December 2014 / Accepted: 25 August 2015 / Published online: 5 September 2015  
© The Author(s) 2015. This article is published with open access at Springerlink.com

**Abstract** Water saving devices in the sanitary equipment, such as flow regulators, are assumed to be environmentally advantageous even though their environmental benefit has never been compared to the environmental burden caused during their production and disposal. Therefore, a life cycle assessment according to ISO 14044 has been conducted to identify and quantify the environmental effects throughout the lifespan of a flow regulator. The analysis comprises the production of materials, manufacturing of components at suppliers, the assembly at NEOPERL<sup>®</sup>, all transports, savings of water and thermal energy during use as well as waste incineration including energy recovery in the end-of-life stage. Results show that the production of one flow regulator causes 0.12 MJ primary energy demand, a global warming potential of 5.9 g CO<sub>2</sub>-equivalent, and a water consumption of 30.3 ml. On the other hand, during a use of 10 years, it saves 19,231 MJ primary energy, 1223 kg CO<sub>2</sub>-equivalent, and avoids a water consumption of 790 l (166,200 l water use). Since local impacts of water consumption are more relevant than volumes, consequences of water consumption have been analyzed using recently developed impact assessment models. Accordingly, the production of a flow regulator causes 8.5 ml freshwater depletion,  $1.4 \times 10^{-13}$  disability adjusted life years, and  $4.8 \times 10^{-6}$  potentially disappeared fractions of species m<sup>2</sup> a. Even though avoided environmental impacts resulting

from water savings highly depend on the region where the flow regulator is used, the analysis has shown that environmental benefits are at least 15,000 times higher than impacts caused during the production.

**Keywords** Life cycle assessment · Water footprint · Climate change · Primary energy demand · Flow regulator · NEOPERL<sup>®</sup>

## Introduction

During the past century, water use was growing twice as fast as the world's population (UN and FAO 2007). Today, 1.2 billion people live in water scarce regions and another 1.6 billion people suffer from economic water shortage. This means they do not have access to safe drinking water due to missing opportunities to withdraw, purify, or transport water from aquifers and rivers (UNDP 2012). As a consequence of climate change, population growth, and changing consumption patterns in emerging nations, water scarcity is expected to increase significantly in many parts of the world (Alcamo and Henrichs 2002).

Attempts to reduce water stress are manifold and reach from river basin management, technological achievements in drinking water purification and waste water treatment, to water saving efforts in daily life. A common approach to reduce domestic water use is the installation of water saving devices in the sanitary equipment. For instance, flow regulators can be mounted in water taps or shower heads and will ensure a near-constant water flow by compensating for changes occurring in line pressure.

As shown in Fig. 1, the NEOPERL<sup>®</sup> flow regulator is composed of a polymer body (green) and a deformable O-ring (black). The O-ring reacts to changes in pressure by

✉ Markus Berger  
markus.berger@tu-berlin.de

<sup>1</sup> Technische Universität Berlin, Chair of Sustainable Engineering, Office Z1, Strasse des 17. Juni 135, 10623 Berlin, Germany

<sup>2</sup> Neoperl GmbH, Klosterrunstraße 9-11, 79379 Müllheim, Germany



**Fig. 1** Image of NEOPERL<sup>®</sup> flow regulator consisting of a body and a dynamic O-ring

adjusting its shape to decrease or increase the amount of water flowing through. As a consequence, the flow rate remains nearly constant. Depending on the line pressure, flow regulators can reduce the water flow by up to 50 % (NEOPERL<sup>®</sup> 2014).

While it is obvious that a flow regulator saves water during its use, it is not easy to say how much water is needed during its manufacturing and during the production of its components and their underlying materials and raw materials. Significant amounts of water can be required in the production of, e.g., crude oil and polymers needed to produce the flow regulator (Berger et al. 2012). Also the generation of electricity needed during the manufacturing processes requires substantial amounts of freshwater (Pfister et al. 2011). In a similar way, the installation of flow regulators does not only save water but additionally avoids energy and greenhouse gas (GHG) emissions resulting from reduced drinking water production, transports, thermal energy production, and waste water treatment. On the other hand, the manufacturing of a flow regulator and the production of the materials and raw materials causes energy consumption and GHG emissions as well.

So which environmental impacts caused in the production and disposal of a flow regulator have to be accepted to achieve the environmental benefits resulting from its installation? This question will be answered in this paper by means of a life cycle assessment study conducted according to ISO 14044 (2006).

## Life cycle assessment of a NEOPERL<sup>®</sup> flow regulator

### Goal and scope definition

The functional unit of this study is the use of one SHL-C 2.5 gpm flow regulator (Fig. 1) over an expected lifetime

of 10 years. The savings of water and thermal energy have been calculated as follows:

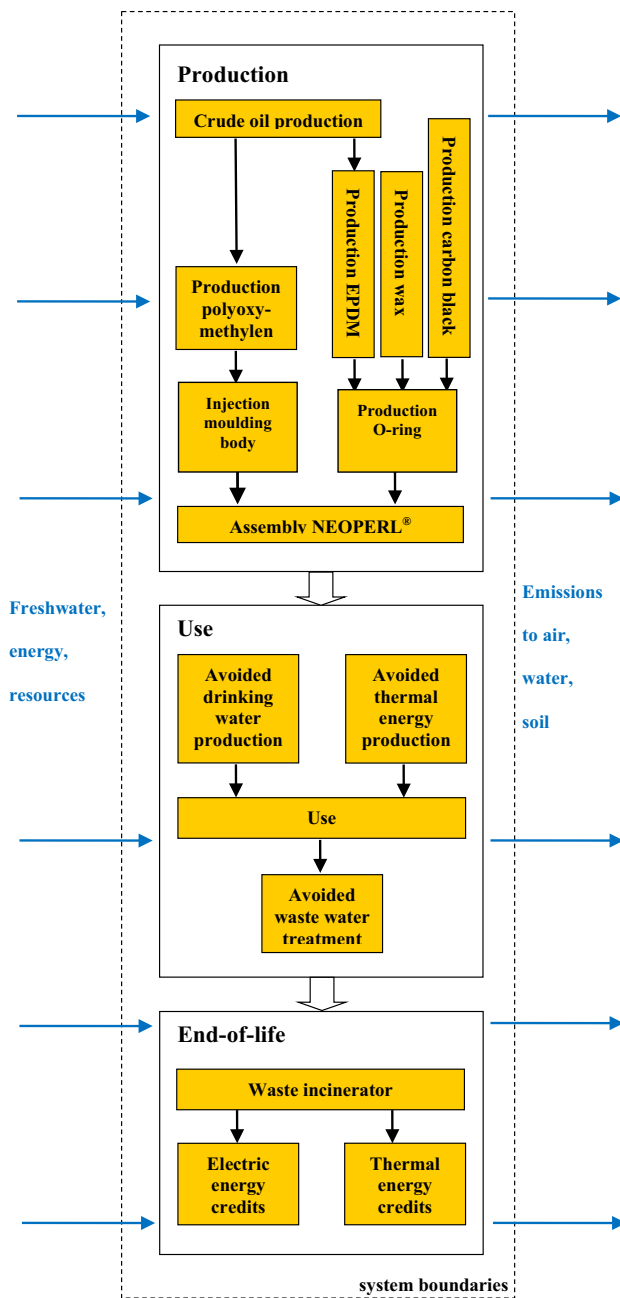
A two person household has been assumed in which each person takes 300 5-min showers per year. By installing a flow regulator, the water flow is reduced from 15 l/min to 9.46 l/min. Over a period of 10 years this results in water savings of 166,200 l. Assuming an inlet water temperature of 10 °C and a shower temperature of 37 °C along with a specific heat capacity of 4.19 kJ/(kg K), this leads to an avoided thermal energy provision of 4831 kWh.

As requested by ISO 14044, the full product life cycle has been considered consisting of the main phases production, use, and end-of life. The production stage comprises the production of raw materials and materials, the manufacturing at suppliers, and the assembly at NEOPERL<sup>®</sup>. In the use phase environmental benefits resulting from avoided drinking water production, thermal energy production, and waste water treatment are taken into account. Finally, waste incineration including energy recovery is considered in the end-of-life stage. Figure 2 shows the various processes involved in the production of the flow regulator's body and O-ring, as well as the avoided drinking water production, thermal energy generation, and waste water treatment. Also the disposal of the flow regulator, which comprises a waste incineration with electric and thermal energy recovery, is included.

Since the flow regulator consists of two components only, no cut-off criteria have been applied in the foreground system and in the material production modeling. Regarding data requirements, inventory data shall represent production and usage in Germany (to be altered in sensitivity analyses, [Life cycle interpretation](#)) and shall not be older than 2012. In order to assess environmental consequences, this LCA focuses on primary energy demand, global warming, and water consumption (incl. resulting impacts). Despite the fact that the terms water use and water consumption are often used synonymously, it should be noted that their meaning is different. As defined in the new international standard on water footprint ISO 14046 (2014), water use comprises the total water input into a product system, i.e., the withdrawal of ground and surface water. In contrast, water consumption is defined as the fraction of water use which has become unavailable for the originating river basin due to evapo(transpi)ration, product integration, or discharge into other basins and the sea. Since only a relatively small fraction of total water use is actually consumed, this work focuses on water consumption in line with ISO 14046 (2014).

### Life cycle inventory analysis

The life cycle inventory (LCI) step comprises the identification and quantification of all elementary flows entering



**Fig. 2** System boundaries showing the processes considered in the LCA of the flow regulator (transportation processes are not shown)

to or leaving from processes within the product system (ISO 14044 2006). This includes resource inputs such as iron ore, crude oil, or freshwater as well as waste and emission outputs like GHG emissions to air, phosphates to rivers, or heavy metals to soil.

The elementary flows entering to or leaving from the product system of a NEOPERL® flow regulator have been determined for each of the processes shown in Fig. 1. For the foreground system, i.e. the assembly of the flow regulator at NEOPERL® and the manufacturing of the body and

the O-ring at suppliers, this data has been measured and/or determined from records such as electricity or water bills. The elementary flows of the basic material production, e.g., polyoxymethylene (POM) for the body or ethylene propylene diene monomer (EPDM) used in the O-ring, have been determined from the GaBi 6 database (Thinkstep 2015). This LCI database contains the environmental profile, i.e. the complete inventory of elementary flows, for more than 8000 materials as well as manufacturing, transport, waste water treatment, or waste incineration processes. It should be noted that inventory data obtained from the GaBi database has been verified by NEOPERL®’s Research and Development department. This means plausibility of the datasets has been checked based on literature reviews, physical and chemical calculations as well as own measurements. As shown in Fig. 3 for the production phase, the generic LCI datasets from the GaBi database for the material production are combined with the primary data determined for the production and assembly processes at NEOPERL® and its suppliers.

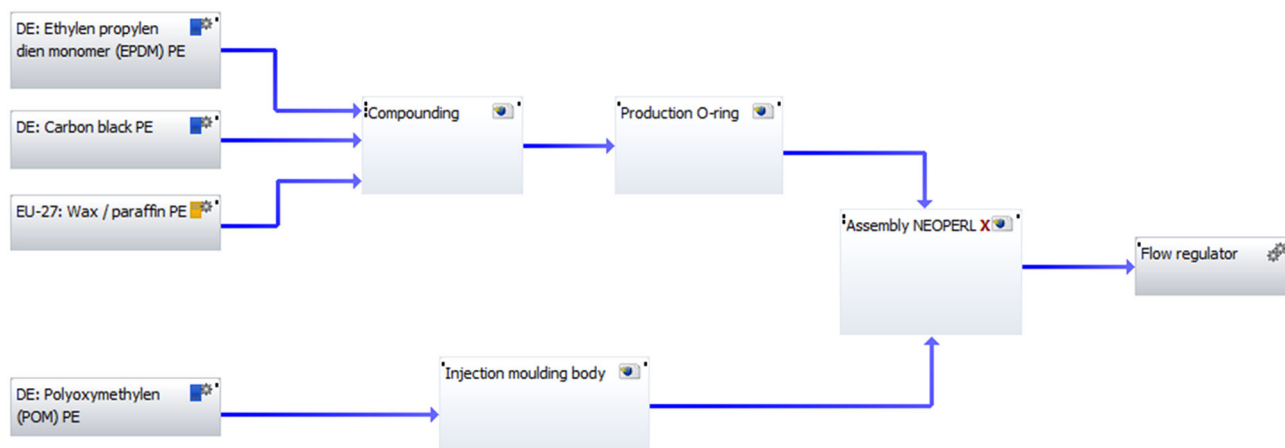
Regarding water, a traditional LCI which aggregates the volumes of water consumption is not sufficient to enable the determination of resulting impacts. As freshwater scarcity differs regionally and since the adaptation capability of nature and humans depends on the local sensitivity of ecosystems and the degree of development, spatial information needs to be included (Bayart et al. 2010; Kounina et al. 2013).

The water consumption in the foreground system, i.e., in the assembly at NEOPERL® and in the production of the body and O-ring at suppliers, can be regionalized easily by tracking the supply chains. In contrast, there is no such easy way to regionalize the water consumption in the background system, i.e., in the production of the underlying materials like POM or EPDM, as this information is not available in today’s LCI databases (Berger and Finkbeiner 2013). Therefore, the top-down regionalization approach developed in a previous study (Berger et al. 2012) has been applied. First, a material’s total water consumption has been disaggregated into the water consumption of the individual production steps. Subsequently, the water consumption of the individual production steps is allocated to specific countries based on statistical import mixes and production sites.

As a result, a spatially explicit water inventory has been created, which contains the volumes of water consumed in the different regions of the world. As shown in Fig. 4, the production of a NEOPERL® flow regulator causes water consumption in 22 countries around the globe. A relatively small fraction of water is consumed in Northern Africa, Saudi Arabia, Iraq, Kazakhstan, and Russia resulting from the production of crude oil used for the production of the POM body and EPDM used in the O-ring. More than 95 %

## Production flow regulator

GaBi Prozessplan: Referenzgrößen



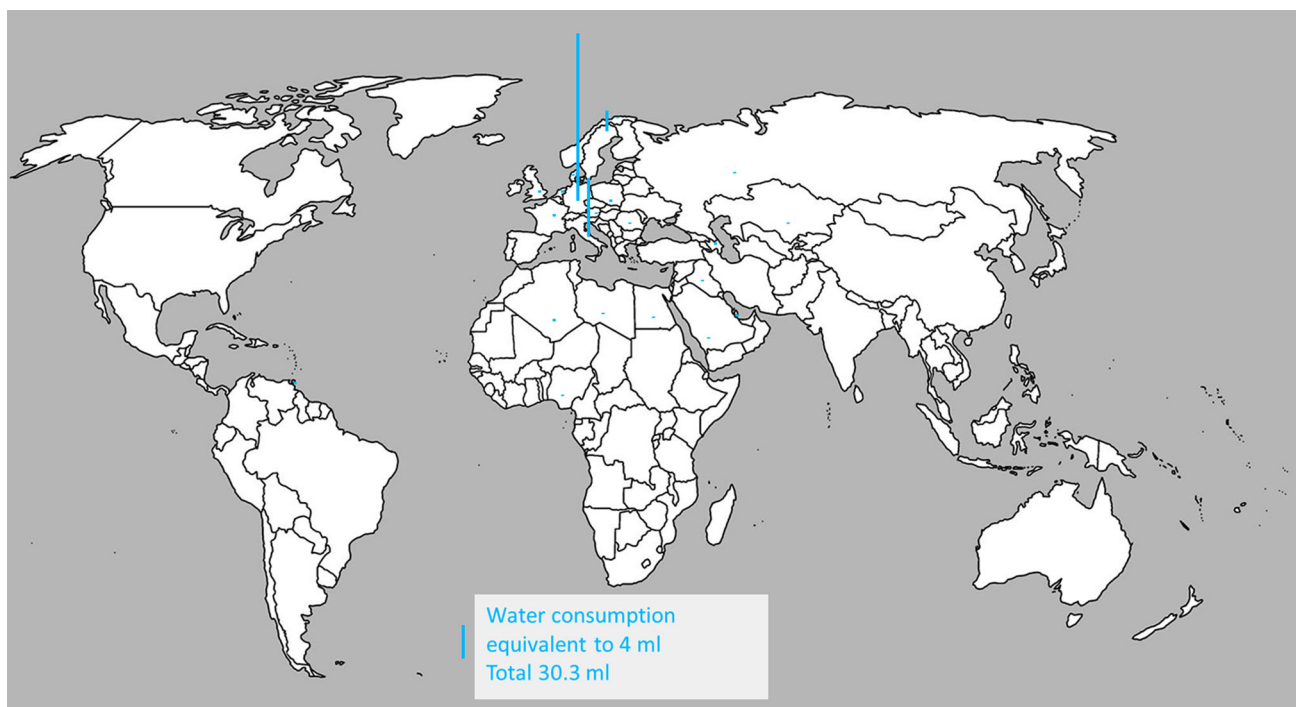
**Fig. 3** LCI modeling of the production of a flow regulator accomplished in the GaBi 6 LCA software (Thinkstep 2015)

of the water consumption occurs in Germany, Italy, and Sweden resulting to about 50 % from the electricity consumption of the production processes of NEOPERL® and suppliers.

### Life cycle impact assessment

Based on the LCI established in the previous step, environmental consequences resulting from the elementary flows, which have been extracted from or emitted to the

ecosphere, have been determined in the life cycle impact assessment (LCIA). According to the international standard (ISO 14044 2006), each elementary flow has been assigned to the environmental impact category it influences (classification). To quantify the environmental relevance of the substance, each flow is multiplied by a characterization factor, which has been determined in a characterization model that describes the environmental mechanism. For instance, all greenhouse gases emitted from the product system have been assigned to the impact category climate



**Fig. 4** Spatial distribution of water consumption occurring in the production of a NEOPERL® flow regulator



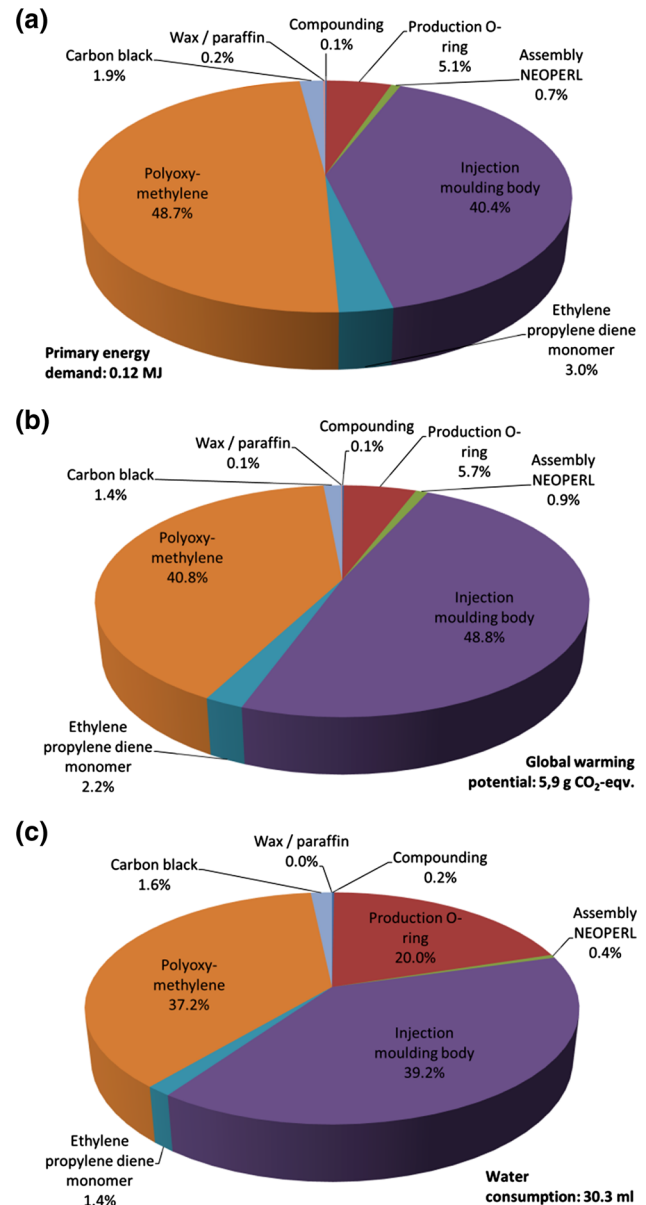
change. Then, each greenhouse gas emission is multiplied by its characterization factor denoting the respective radiative forcing in relation to the reference substance (CO<sub>2</sub>). Finally, the individual characterized emissions are aggregated to quantify the global warming potential of the product system expressed in CO<sub>2</sub>-equivalents.

As stated in the goal and scope definition, this work focuses on the primary energy demand, climate change, and water. For the determination of the primary energy demand all renewable and non-renewable energy sources entering the product system are aggregated—regardless of whether they are used for the generation of electric or thermal energy or in the production of polymers. In the impact category climate change, all greenhouse gas emissions are multiplied by their respective global warming potential (kg CO<sub>2</sub>-equivalents) derived from the characterization model developed by Leiden University (Guinee et al. 2002, update 2013). Water consumption is first evaluated on a volumetric level but subsequently resulting impacts are assessed by means of the characterization models of Pfister et al. (2009) and Berger et al. (2014) which are described later on.

Results show that the production of 1 flow regulator consumes 0.12 MJ of primary energy, causes 5.9 g CO<sub>2</sub>-equivalent of GHG emission, and consumes 30.3 ml of water. As shown in Fig. 5, the production of POM and the electricity consumed in the injection molding of the body are responsible for 76–90 % of the environmental burden depending on the category. In contrast, the assembly of the flow regulator at NEOPERL® causes less than 1 % of the environmental impact in each category. While the production of the O-ring at a supplier is responsible for 5–20 % of the environmental burden, the production of wax/paraffin, carbon black, EPDM and the compounding of the O-ring material cause 3–5 % of the impacts together.

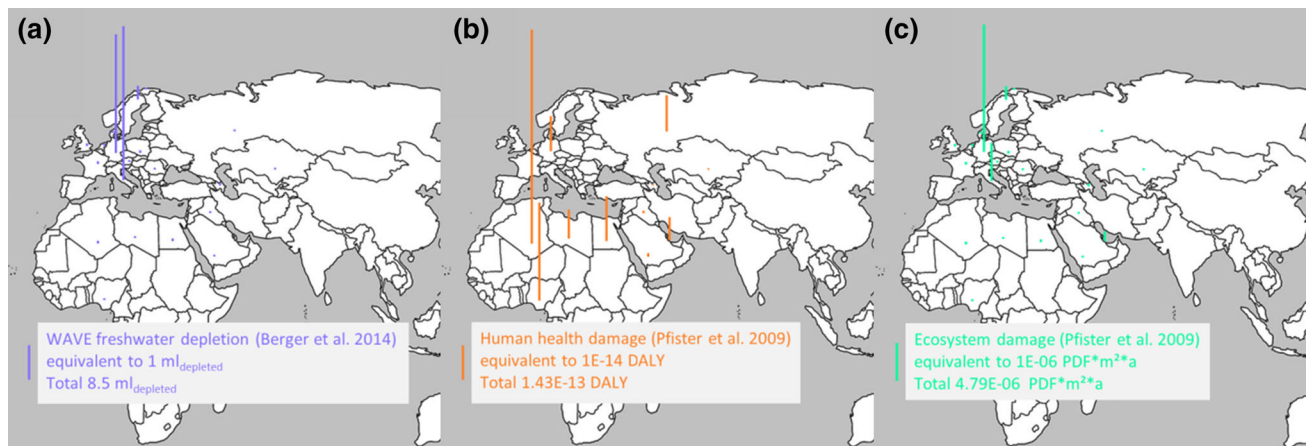
Regarding the assessment of impacts resulting from water, the regional water consumption figures shown in Fig. 4 are multiplied by their corresponding regional characterization factor derived from the characterization models of Pfister et al. (2009) and Berger et al. (2014). The impact category freshwater depletion developed in the water accounting and vulnerability evaluation model (WAVE) determines the risk that water consumption in a region leads to a depletion of freshwater resources based on local water scarcity (Berger et al. 2014). The impact assessment method developed by Pfister and colleagues comprises (amongst others) two damage assessment models which describe the cause-effect chains of water consumption leading to malnutrition induced human health damage and ecosystem damage resulting from reduced net primary production (Pfister et al. 2009).

From Fig. 6 it can be seen that impacts resulting from water consumption lead to different findings than the



**Fig. 5** Relative contributions of the materials and production steps to the overall environmental impacts in the production of a NEOPERL® flow regulator regarding **a** primary energy demand, **b** climate change, and **c** water consumption

volumetric water inventory shown in Fig. 4. In the impact category freshwater depletion (Fig. 6a), water consumption in Italy, which mainly results from the polymerization of EPDM at NEOPERL®'s supplier in Italy, is weighted much higher than on the inventory level due to the relatively high freshwater scarcity. In contrast, water consumption in Sweden resulting from the formaldehyde production, which is used as a chemical precursor for the POM production, causes hardly any impacts here as water is abundantly available. Considering potential damages on human health (Fig. 6b) reveals that very low amounts of water consumed



**Fig. 6** Regional impacts resulting from the water consumption in 22 countries during the production of a flow regulator regarding **a** freshwater depletion, **b** human health damages, **c** ecosystem damages

during crude oil production in water scarce and developing countries like Algeria, Nigeria, Libya, or Egypt dominate this impact category. However, it should be noted that the total potential damage of  $1.43 \times 10^{-13}$  disability adjusted life years (DALY, Murray and Lopez 1996) is extremely low. Despite scarcity, the relatively large share of water consumption in Italy does not cause any damages to human health due to the high degree of development which enables compensation strategies and avoids water scarcity related health effects. With regard to potential ecosystem damages the degree of development does not influence the magnitude of impacts. Moreover, ecosystems in dry countries are adapted to freshwater scarcity. That's why Fig. 6c shows similar results as the water inventory (Fig. 4).

So far, the environmental impacts have been analyzed during the production phase only. Taking a life cycle perspective, the environmental benefits resulting from the avoided drinking water production of 166,200 l as well as the avoided thermal energy production and waste water treatment are taken into account. Moreover, the impacts caused by the waste incineration and the benefits from the energy recovery in the end-of-life phase are taken into account.

As shown in Fig. 7, a flow regulator leads to net-savings of 19,231 MJ of primary energy, 1223 kg CO<sub>2</sub>-equivalent, and 790 l of water consumption (166,200 liters of water use). It becomes obvious that the savings of primary energy, greenhouse gas emissions, and freshwater are by far larger than the impacts caused during the production. It is also interesting to note that more than 95 % of the environmental benefit concerning primary energy demand and climate change result from the avoided production of thermal energy needed to heat the showering water. In contrast, the water savings are dominated by the avoided water consumption resulting from losses in the drinking water production (68 %). Avoided thermal energy

production causes only 5 % of the savings, as thermal energy production from natural gas hardly consumes any water. Another 27 % of water savings result from the avoided evaporation of water during the showering.

Until now savings regarding water consumption have been discussed on a volumetric level only as an evaluation on the impact level strongly depends on the region where the flow regulator is used. This relevant issue has been addressed in the following sensitivity analyses accomplished in the life cycle interpretation phase.

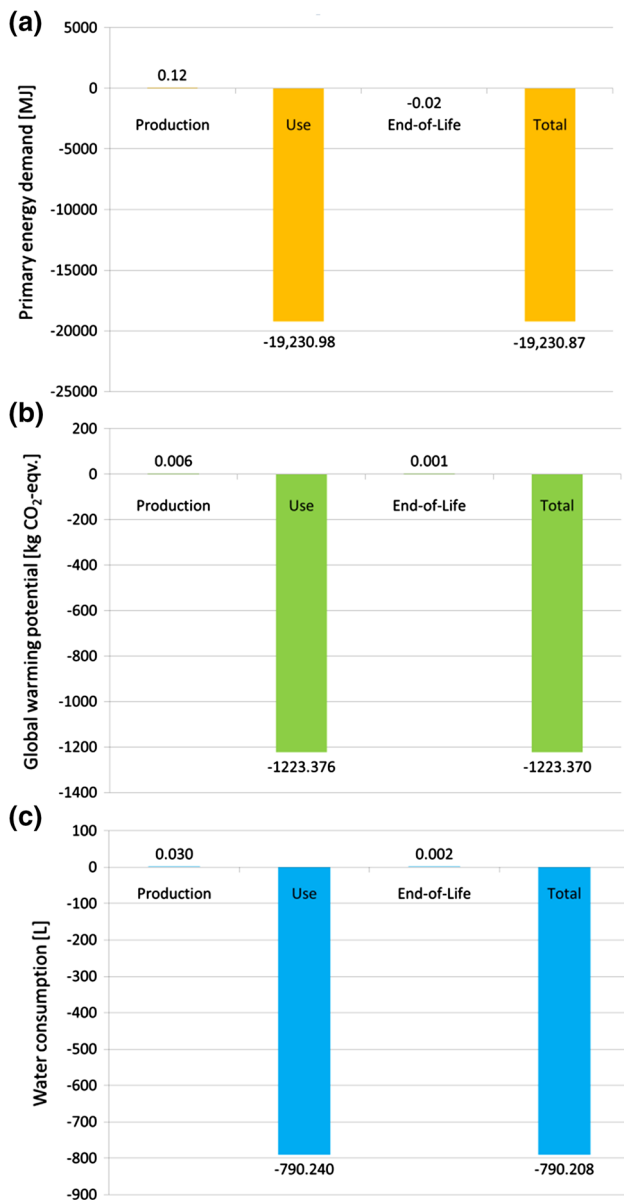
Figure 7 also shows that impacts of the end-of-life are negligibly low compared to the use phase and to the production. This can be explained by the fact that waste incineration including energy recovery has been assumed as the most likely end-of-life scenario of a polymer-based product. Consequently, environmental impacts resulting from the waste incineration are reduced by credits gained from the avoided primary production of thermal and electric energy. In case of the primary energy demand, this leads to a slightly negative result even.

Further environmental impact categories such as eutrophication, acidification, photochemical ozone creation, human- and eco-toxicity have been analyzed as well. However, they are not addressed explicitly in this paper as their results are very similar to the ones discussed above.

### Life cycle interpretation

The final life cycle interpretation step of an LCA aims at interpreting results obtained in the LCI and LCIA phases in order to draw conclusions and give recommendations. It mainly comprises the identification of significant parameters and their evaluation by means of completeness, consistency, and sensitivity analyses (ISO 14044 2006).

As shown in Fig. 5, the production of POM and the injection molding of the body are the most relevant



**Fig. 7** Environmental impacts caused along the life cycle of a NEOPERL® flow regulator regarding **a** primary energy demand, **b** global warming potential, and **c** water consumption

processes in the production of a flow regulator. That is why the underlying data have been confirmed regarding completeness and consistency with the requirements defined in the goal and scope definition. The most important life cycle phase is the use phase in which environmental benefits are created due to water savings and associated avoided thermal energy production. The magnitude of these environmental benefits depends strongly on the assumptions made in the goal and scope definitions. However, since the results of this study are so unambiguous, even strong variations from the underlying assumptions would not change the conclusions drawn from this study. Therefore,

no quantitative sensitivity analysis is presented in this work.

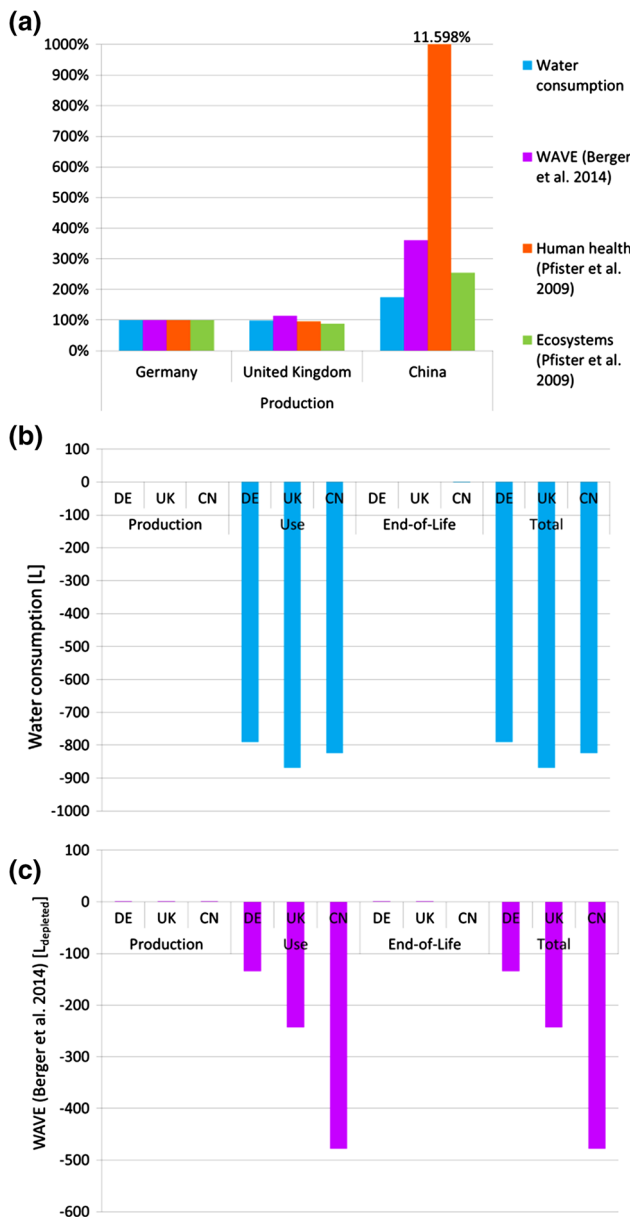
As mentioned in the LCIA, impacts and benefits resulting from water consumption and savings depend strongly on the region in which the consumption or saving occurs. For this reason, sensitivity analyses are conducted which evaluate the consequences of spatially shifted production and application of the flow regulator. In addition to the scenario of production and application in Germany, it is analyzed how the results change if production, use, and end-of-life took place in the United Kingdom and in China.

Figure 8a shows the water consumption and the resulting impacts normalized to the German baseline scenario. While the United Kingdom scenario leads to similar results, the Chinese scenario leads to different findings. With 53 ml, the production of a flow regulator causes higher water consumption than the production in Germany (30 ml). The reason for this increase can mainly be found in the underlying electricity mixes. In China fossil energy carriers have a higher share in electricity production, which leads to an increased water consumption due to higher cooling water demands (Thinkstep 2015). However, the main difference can be found on the impact assessment level. While freshwater depletion increases from 8.5 to 30.8 ml, potential damages to human health increase by more than 11,000 %. This can be explained by a higher physical water scarcity in China and by a comparably lower compensation capability which cannot avoid health impacts as efficiently as in Germany.

When taking a life cycle perspective, water savings in the use phase clearly dominate the overall result (Fig. 8b). Water savings in the United Kingdom are highest, as the avoided production of thermal energy from natural gas shows a relatively high water intensity compared to Germany and China. With regard to avoided impacts resulting from water savings, Fig. 8c shows that water savings in China lead to a significantly higher benefit than the water savings in Germany or in the United Kingdom. Thus, the significantly higher impacts resulting from the higher amount of water consumed in the Chinese production of a flow regulator are more than compensated due to the great benefits that are obtained when saving water in water scarce countries like China.

## Conclusions

Even though it has been assumed that water saving devices in the sanitary equipment, such as flow regulators, are environmentally advantageous, their impacts on and benefits for the environment have never been analyzed in detail. Therefore, an LCA according to ISO 14044 (2006) has been accomplished in order to quantify the



**Fig. 8** **a** water consumption and resulting impacts in the United Kingdom and China normalized to the German basic scenario, **b** water balance along the life cycle of a flow regulator in Germany, United Kingdom, and China, **c** impacts concerning freshwater depletion resulting from the water balance shown in **b**

environmental impacts and benefits throughout the life cycle of a NEOPERL<sup>®</sup> flow regulator.

The analysis covers the production of one flow regulator, water savings of 166,200 l as well as thermal energy savings of 4831 kWh during the use phase, and the waste incineration including energy recovery in the end-of-life stage. The LCI has been established by means of the GaBi 6 LCA software. Data for the foreground system comprising the assembly at NEOPERL<sup>®</sup> and the production of the body and O-ring at its suppliers has been measured

directly. In order to analyze the environmental impacts of the background system, comprising raw material and material production as well as energy production and transportation, generic LCI datasets from the GaBi 6 database have been used. Results of the LCIA show that the production of one flow regulator causes 0.12 MJ primary energy demand, a global warming potential of 5.9 g CO<sub>2</sub>-equivalent, and a water consumption of 30.3 ml. On the other hand, during a use of 10 years it saves 19,231 MJ primary energy, 1223 kg CO<sub>2</sub>-equivalent, and avoids a water consumption of 790 l (166,200 l water use). Rather than discussing volumes, water should be analyzed on the impact assessment level. That's why a spatially explicit water inventory has been created and consequences of water use have been analyzed using recently developed impact models. Accordingly, the production of a flow regulator causes impacts of 8.5 ml freshwater depletion,  $1.4 \times 10^{-13}$  DALY, and  $4.8 \times 10^{-6}$  potentially disappeared fractions of species (PDF)\*m<sup>2</sup> a. Avoided impacts resulting from water savings in the use phase are highly dependent on the region where the flow regulator is installed. However, results of a sensitivity analysis show that advantages on the impact assessment level are in a similar range than on the volumetric level. It can be concluded that the use of a flow regulator saves about 160,000 times the primary energy, 204,000 times the global warming potential, and 26,000 times the water consumption that result from its production. In order to answer the question raised in the title of this paper, it can be said that about 38 ml of water consumption are needed to save 1 m<sup>3</sup> of water.

**Acknowledgments** This research was accomplished by TU Berlin which has been commissioned by NEOPERL<sup>®</sup>. The authors want to express sincere thanks to the suppliers who contributed to this work by providing valuable inventory data of their production processes.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

## References

- Alcamo J, Henrichs T (2002) Critical regions: a model-based estimation of world water resources sensitive to global changes. *Aquat Sci* 64:352–362
- Bayart JB, Bulle C, Koehler A, Margni M, Pfister S, Vince F, Deschenes L (2010) A framework for assessing off-stream freshwater use in LCA. *Int J Life Cycle Assess* 15(5):439–453
- Berger M, Finkbeiner M (2013) Methodological challenges in volumetric and impact oriented water footprints. *J Ind Ecol* 17(1):79–89



- Berger M, Warsen J, Krinke S, Bach V, Finkbeiner M (2012) Water footprint of European cars: potential impacts of water consumption along automobile life cycles. *Environ Sci Technol* 46(7):4091–4099
- Berger M, van der Ent R, Eisner S, Bach V, Finkbeiner M (2014) Water accounting and vulnerability evaluation (WAVE)—considering atmospheric evaporation recycling and the risk of freshwater depletion in water footprinting. *Environ Sci Technol* 48(8):4521–4528
- Guinee JB, Gorree M, Heijungs R, Huppes G, Kleijn R, de Koning A, van Oers L, Sleeswijk AW, Suh S, Udo de Haes HA, de Bruijn H, van Duin R, Huijbregts MAJ (2002) Life cycle assessment—an operational guide to the ISO standards. *Eco-efficiency in industry and science*, vol 7. Kulwer Academic Publishers, Dordrecht
- ISO 14044 (2006) Environmental management—life cycle assessment—requirements and guidelines (ISO 14044:2006). Geneva, Switzerland
- ISO 14046 (2014) Water footprint—principles, requirements and guidance Geneva, Switzerland
- Kounina A, Margni M, Bayart J-B, Boulay A-M, Berger M, Bulle C, Frischknecht R, Koehler A, Canals LMI, Motoshita M, Núñez M, Peters G, Pfister S, Ridout B, Zelm RV, Verones F, Humbert S (2013) Review of methods addressing freshwater use in life cycle inventory and impact assessment. *Int J Life Cycle Assess* 18(3):707–721
- Murray C, Lopez A (1996) The Global Burden of Disease. Harvard School of Public Health (on behalf of the World Health Organization, World Bank), Boston, MA, USA
- NEOPERL® (2014) Available at: <http://www.waterlimited.net/en/wl/savingwater/howdoesitwork.html>. Accessed 15 Nov, 2014
- Thinkstep (2015) GaBi LCA software and database. Available at <http://www.gabi-software.com>. Accessed 31 Aug 2015
- Pfister S, Koehler A, Hellweg S (2009) Assessing the environmental impacts of freshwater consumption in LCA. *Environ Sci Technol* 43(11):4098–4104
- Pfister S, Saner D, Koehler A (2011) The environmental relevance of freshwater consumption in global power production. *Int J Life Cycle Assess* 16(6):580–591
- UN and FAO (2007) Coping with water scarcity—challenge of the twenty first century. Paper presented at the 2007 World Water Day
- UNDP (2012) Human development reports. Available at <http://hdr.undp.org/en/statistics/>. United Nations Development Programme. Accessed 20 June, 2014