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WATER-ENERGY NEXUS IN URBAN WATER UTILITIES: A BRIEF NORWEGIAN OUTLOOK

Vann-energi nexus i urbane vannverk: et norsk perspektiv

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Abstract

Urban water utilities have realised the importance and the possibility of improving the energy efficiency of their operations; and also have started looking at urban water utilities as essentially energy-producers. The driving factors are economic issues, environmental goals, self-image, public demands etc. Even Norway which enjoys an abundance of clean and green energy and freshwater, and is among the richest in the world in terms of per-capita GDP, ought to take energy efficiency in urban water utilities seriously. Of late, politicians, researchers and decision-makers in public organisations have set the ball rolling briskly in this direction.

Key words – Water-energy nexus, energy efficiency, Urban water utilities, Norway

Sammendrag

Urbane vannverk har nå akseptert at det er både nødvendig og mulig å effektivisere sine operasjoner. De har også begynt å se på dem selv som energiprodusenter. Faktorene som gjør det nødvendig er økonomiske og miljømessige; og også politiske og sosiale. Selv Norge som er begavet med massevis av ren og grøn energi og ferskvann, og er blant de rikeste i verden (basert på BNP pro innbygger), må ta energi-effektiversing alvorlig. Politikere, forskere og de ansatte i offentlige organisasjoner har satt et eksempel i denne retningen.

Introduction and approach

The water-energy nexus, both the use of energy in urban water utilities and the use of water in the energy sector, has merited a lot of attention in the recent past, owing to the fact that while these two are intricately interlinked, scarcity issues associated with one can impact on the availability of the other in the form and quantity desired. Water utilities have realised the importance and the possibility of improving the energy efficiency of their operations; and also have started looking at urban water utilities as essentially energy-producers. This realisation is global and the need for the same, is global as well. The driving factors are usually a combination of economic issues, environmental goals, self-image, public demand etc.

This paper focuses on the extent to which the water-energy nexus (as applied to the use of energy in urban water systems) is treated in Norway, a country blessed with an abundance of both clean energy and freshwater. The authors solicited feedback from personnel in water utilities in the country by despatching the set of questions listed in Table 1. The response rate was quite poor, unfortunately; with the common refrain being preoccupation with more pressing concerns at the utilities. The paper has been fashioned out of the opinions which were shared with the authors, all by personnel from the water utility in the capital city Oslo.

A discussion based on the responses obtained from the utilities follows a brief review of published papers related to the water-energy nexus outside and within Norway.

Another set of questions was also despatched to the 'common Norwegian citizens'; ensuring a good diversity in backgrounds. The e-mail route was employed again, and the authors reached across to Norwegian friends and acquaintances, directly and also via colleagues. The questionnaire was sent out to about 55 potential respondents, of which 27 eventually responded (a response rate of slightly under 50 %). This questionnaire has been reproduced in Table 2. The responses received are discussed in the next section of this article (the respondents have been acknowledged at the end of the paper). Owing to time constraints, the number of responses was not very high; but yet, in the authors' opinion, sufficient to warrant an overview-discussion of the perceptions of Norwegian citizens (related to the water-energy nexus). Of course, it must be mentioned, that the meaningfulness and robustness of a survey of this nature is directly proportional to the total number of complete responses received.

Literature Review

A search for the term '*water-energy nexus*' in the keywords and/or the abstract of the clutch of water journals published by the International Water Association, and the journals Urban Water Journal, Water Research and Energy, did not yield many matches as far as published scientific papers related to urban water utilities are concerned. The earliest publication is from the year 2008 and focuses on China (Kahrl et al, 2008). Lenouvel et al. al. (2014) working from France, have studied the water-energy nexus in the island nation of Singapore. They observe, *inter alia*, that 2.0 % of the Singaporean electricity demand is already dedicated to water and wastewater treatment processes; and if its water-energy footprint dramatically increases in the coming decades, ambitious research projects may buffer the energy cost of water self-sufficiency. In Haley et al. (2012), water conservation in California has been mooted as an important mitigation strategy when it comes to reducing energy consumption and cutting back greenhouse gas emissions. Chong et al. (2013), working on an Australian case study, have compared two approaches to producing recycled water (water scarcity is a growing concern in Australia). Kahrl et al. (2008) working from California and focusing on China, had, in the last decade, examined the nexus between two of China's scarcest resources – energy and water, while focusing on the energy implications of water use. They had advocated the use of lifecycle assessment frameworks in the evaluation of projects in the water sector to aid policymakers in choosing en-

Table 1. *Questions addressed to personnel at the four urban water utilities.*

1. Since when did your utility actually start focusing on energy efficiency issues? What was the trigger or the main driving factor?
2. Can you comment on what the utility has done thus far to improve energy efficiency across the system? And what are the plans on the anvil now?
3. How do you reconcile with the economics of energy efficiency improvements? At times, the investments are huge, but the perceptible benefits are quite low, and the ROI-period is sufficiently long…I gather that Norwegian water utilities would find it relatively easy to get loans at attractive interest rates and would not have major problems paying back?
4. Can you comment on the stream of investments made specifically into energy efficiency improvement in the system over the last 5 years?
5. Do you also factor in the consumption of energy in households and end-users' sites, related to water use? This in fact in beyond the purview of water utilities, but accounts for a huge chunk of energy use, if this is also factored into the water-sanitation system!
6. Norway is gifted with clean electricity, lots of water and also is a rich nation. Is abundance a curse in this case or some kind of obstacle, which makes one think again and again about the need for energy efficiency?
7. Any documented improvement over the years in indicators related to system-wide energy use in the utility? In per-capita or per-unit-volume-water-demand-supplied terms? Do you systematically record these indicators in order to serve as a guide in decision-making?
8. Is there sufficient pressure or encouragement from policy-makers in the city, provincial, national or regional governments to improve energy efficiency, in your opinion?
9. 'Energy for water' in urban water systems cannot be seen in isolation from the capacity of urban water systems to generate energy. Could you comment on efforts being made at your utility to recover energy from the sub-systems? Biogas, micro-turbines etc….?

Table 2. *Questionnaire despatched to randomly-selected Norwegian consumers of water and sewerage services from utilities.*

1. On a scale of 1 to 10, where '1' is 'serious concern' and '10' is 'no concern at all', where in your opinion would water availability in Norway in the future, be?
2. On a scale of 1 to 10, where '1' is 'serious concern' and '10' is 'no concern at all', where in your opinion would electricity availability in Norway in the future, be?
3. In your opinion, will using water optimally in households and industries, lead indirectly to energy savings?
   i. Yes, surely; ii. Not sure; iii. Do not think so
4. Would you, if asked to, pay more to enable water utilities to improve their energy efficiency?
   i. Certainly; ii. Not sure; iii. Not at all
5. Your age-group
   i. 21–30; ii. 31–40; iii. 41–50; iv. 51–60; v. 61 and more
6. Your State of residence in Norway

ergy-efficient modes of water provision. Of course, when water is scarce, the government needs to focus on providing adequate water of good quality to the consumers. However, if energy is also scarce, the situation becomes all the more challenging. In another Australian case study, Kenway et al. (2011) has observed that energy use for water supplies Down Under is forecast to rapidly escalate, increasing by 300 % in the period 2007–2030. They point out that there is a lack of a unifying theoretical framework and consistent methodology for the analysis of the water-energy nexus in cities and countries. Writing from Canada and focusing on New York city, da Costa Silva (2014), has proposed the DPSIR (Driving Forces, Pressures, States, Impacts, Responses) model tailored to the water-energy nexus at an urban scale. The author is of the opinion that this model can serve as an effective benchmark to verify and build climate change action plans for cities.

Duong et al. (2011) have used the Israelite capital Tel Aviv as a case to study ways and means to improve the sustainability of urban water systems. Using four strategies – rainwater harvesting, stormwater use, permeable pavements and wastewater reuse – the authors have studied the effect on total water imported into the city. Rainwater harvesting accomplishes a reduction of 10 % and wastewater reuse, 32 %. Wastewater reuse has also been shown to reduce the energy consumption from 2.89 kWh per cubic metre to 2.45 kWh. In a very interesting paper, Santhosh (2014) have written about the co-optimisation method for the economic dispatch of water, power and co-production facilities, with focus on Singapore and the Middle East as cases. The authors have shown in that paper that water storage facilities can reduce total operating costs by up to 38 %; thus having a key role to play in the water-energy nexus. Interestingly, the authors have talked of this nexus as 'energy-water nexus'.

Liang et al. (2011), a paper which must be read along with Kahrl et al. (2008), have stated that the implementation of energy policies and water technology development can produce co-benefits for each other; according to them, from the viewpoint of the proportion of energy saving and carbon dioxide mitigation co-benefits of water technology development, the water sector would benefit the most.

In Norway, which is the focus of this paper, published works in international journals on the water-energy nexus have been limited. Venkatesh and Dhakal (2012) have presented an account of the findings from the workshop held in Tokyo in March 2012, under the auspices of the Global Carbon Project – *Water-energy-carbon nexus in cities: Drivers, Footprints and Implications.* Venkatesh, Brattebø and Sægrov (2014) have published results of the tests carried out for the water utility in Oslo, using the Dynamic Metabolism Model developed at the Norwegian University of Science and Technology, as part of the EU project – Transition to Urban Water Services of Tomorrow. Among other things, the model is capable of capturing the water-energy-carbon nexus associated with interventions which utilities would carry out. The DMM, as it is known in short, is a mass-balance and metabolism-based model which provides as outputs key performance indicators which utilities could find useful in their decision-making process. Also applied to Oslo is another model called WaterMet^2 (also developed as part of the said EU project), developed at the Exeter University in the UK (Behzadian et al., 2014). Larsen (2011), in a superbly informative report on energy consumption in water utilities in Norway, written for Norsk Vann BA, on behalf of MiSA AS, Norway, observes that in year-2009, all Norwegian water utilities taken together consumed 840 GWh of energy for all operations ranging from water treatment to wastewater treatment and discharge. This was equivalent to 156 million kg of CO_2-eq GHG emissions. While the Oslo water utility consumed 140 kWh per capita in its operations, the next two big cities Bergen and Trondheim, consumed only 80 kWh per capita each, in that year. Figure 1 based on the research carried out for that report, charts the historical energy consumption in the Norwegian water utilities, broken up into the four subsystems – water treatment, water distribution, wastewater treatment and wastewater transport. One can see that there has been no appreciable change in the absolute energy consumption over time, indicating perhaps efforts at improving energy efficiency, even as the population and thereby the volumes of water and sewage handled increased. In Venkatesh and Ugarelli (2011), Per Kristiansen, the present Director of the Oslo Vann og Avløpsetaten (Oslo VAV, or the Oslo water utility in other words), had observed, *'Because water is abundant in Norway, we have not ingrained the 'every drop counts' mentality which prevails among the inhabitants of many countries plagued by water scarcity. Water, as some may argue is never lost forever – recall the hydrological cycle – but wasteful use of water treated to a high degree of purity entails the wastage of embedded energy and chemicals used for treatment and distribution. I would reiterate that creating an awareness of this is essential in Oslo and Norway as a whole, irrespective of the abundance of fresh water that the country is blessed with.'*

Most of the water-energy nexus-based studies from Norway have been focused on Oslo. Not all of these however have the term 'water-energy nexus' in the title, keywords or abstract. Venkatesh, Chan and Brattebø (2014) for one, has this term in all three, and in addition to Oslo, that paper also dwells on the cities of Toronto, Turin and Nantes. This paper compares these four cities and attempts to explain how and why the water-energy nexus as applied to urban water utilities varies in degree from one to another. Studies on Oslo focusing *inter alia*, on the consumption and generation of energy by/in the water utility thereof and the associated environmental impacts include Venkatesh and Brattebø (2011a and 2011b), Venkatesh, Brattebø and Hammervold (2011), and Venkatesh and Elmi (2013). Venkatesh (2013) while not exactly focusing on the water-energy nexus per se, describes the historical development of wastewater treatment in Norway (and the influence of policy-making on this development); the focus on biogas generation and energy recovery therefrom tweaks the water-energy nexus a bit to include the generation of some energy by the water utility which is primarily a consumer of energy. Slagstad et al. (2014) have studied the environmental impacts of the consumption of chemicals and energy in the water utility of the central-Norwegian city of Trondheim. The authors observe in that paper that the water utility would have to perform a trade-off between the consumption of energy and chemicals and the discharge of pollutants to receiving waters which causes eutrophication (freshwater eutrophication has been identified as the single largest environmental impact of the urban water cycle in this city). Thus, the point is to not just mind the water-energy nexus but also the water-environment one; bearing in mind that there is a plethora of environmental impacts which merit attention – not just global warming owing to energy consumption.

Results

There was an almost even distribution of the ages of the respondents, as seen from Figure 2, when the range 21–60 is considered. The respondent from the 61–70 age group proved to be an outlier, also in terms of the response given by him/her to Q3. The respondents hailed from 6 different states of Norway, with a large majority of them being based in South Trøndelag, the state in which the Norwegian University of Science and Technology is located, and wherefrom this paper stems. The average score in response to Q1 was 7.22 (refer Figure 3 for the distribution), while that in response to Q2 was 6.26 (refer Figure 4 for the distribution). This goes to show that Norwegians in general are a bit more con-

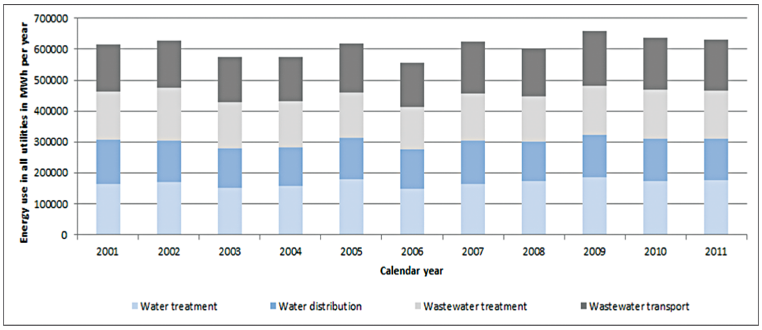

Figure 1. *Annual energy consumption in MWh per year in all the water utilities in Norway (for the period 2001 to 2011). Data courtesy Larsen (2011).*

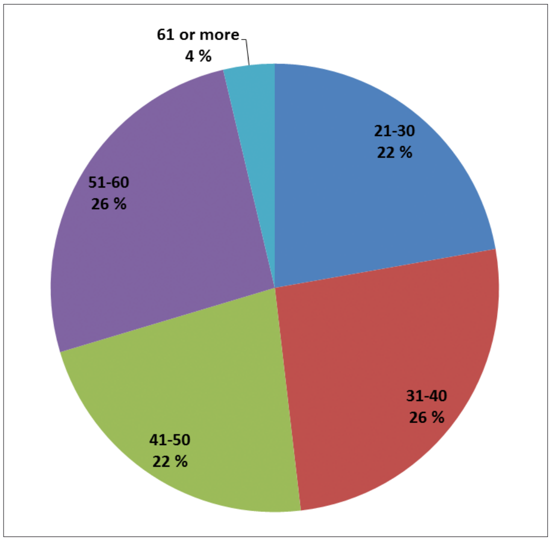

Figure 2. *Age distribution of the respondents of the survey.*

cerned about electricity-availability in the future, vis-à-vis water availability. Yet, in both cases, the average score being closer to 10, than 1, suggests that either of these is not a very big concern.

Out of the 27 respondents, 21 feel that optimising water consumption in households would surely lead to indirect energy savings. This indicates a strong awareness of the water-energy nexus. Of the remaining 6, one does not think so at all; and the fact that he/she is the one in the 61-or-more age group and perhaps has been habituated for long to the abundance of water and energy, may have something to do with the response. He/she also maintains that he/she is not very sure if he/she would be willing to pay to urban water utilities for energy efficiency improvement programs. On the whole, however, as far as willingness to pay is concerned, there is an almost equal split between total willingness on the one hand, and unwillingness/uncertainty on the other.

Discussion

On the 16th of October, 2014, the Norwegian Parliament's Water Group was established. Ketil Kjenseth, the leader of the Venstre (Left) party in the Oppland province of Norway writes in an e-mail correspondence with the authors (related to this paper) that energy efficiency in water treatment would be a big topic for Norwegian Parliamentarians in the near future. This, in his opinion, means that politicians ought to educate themselves about how urban water systems function, and of course about the water-energy nexus which is becoming very central to them these days. He also points out that the European Parliament has, since 2009, had its own EP Water Group. In neighbouring Sweden, the *'Vattennätverk'* (Swedish for 'Water Network') has been doing what the EP Water Group does in the entire EU area. Thus, Norway following suit – better late than never – is a very welcome happening. It would be apt here to flash back to Reinvang et al. (2004) in which the authors had remarked that the process of implementation of the Water Framework Directive (2000/60/EC) in Norway was characterised by lack of domestic political attention and ownership, unclear legal basis for effective decision-making, rivalry between key ministries (the Ministry of Environment and the Ministry of Oil and Energy), inadequate allocation of resources for effective implementation, lengthy delays and lack of public debate and involvement of civil society. As far as the last-cited characteristic goes, it would be well in place at this juncture to

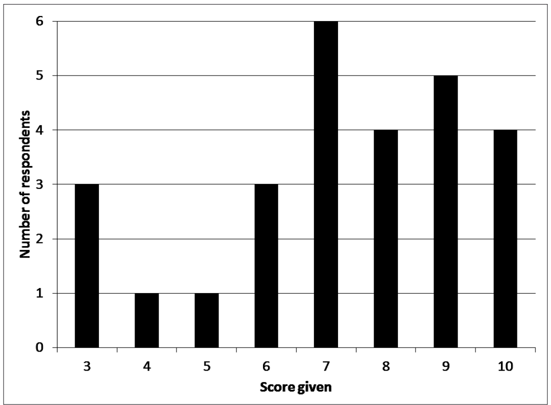

Figure 3. *Distribution of scores given in response to Q1 in the survey.*

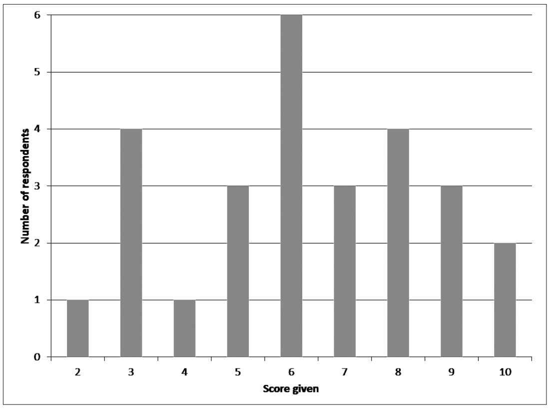

Figure 4. *Distribution of scores in the responses given to Q2 in the survey.*

cite the responses of Lars Hem, Chief Engineer, Oslo VAV, to questions 5 and 6 in Table 1. Hem told the authors that Oslo VAV has, at the time of writing, commenced the practice of laying emphasis on the fact in its campaigns, that optimising the use of warm water provides direct benefits to consumers in terms of reduced energy use and expenses thereon. He also agrees that Norwegian society, thanks to its affluence, and access to abundant, seemingly inexhaustible fresh water, and availability of a continuous, uninterrupted supply of clean hydropower (though perhaps not all know that the Nordic grid from which Norwegian consumers get their electricity also includes thermal power from Denmark or nuclear power from Sweden), is not motivated enough to optimise the use of water and energy. He points out that this is evidenced from the predisposition of the majority in the country to keep the lights on in homes and offices even when there is none inside. To manage the water-energy nexus, involvement of civil society is of paramount importance and policies without factoring in this aspect, may at best be ineffective. What was true in 2004 and remarked by Reinvang et al. (2004), is still valid. Still on civil society, let us refer to EDMS (Hong Kong) Limited (2007), where there is a reference to the fact that according to Norwegian legislation, for properties where no water meter is installed, water consumption is, as a general rule, stipulated on the basis of the size of the buildings. A simple thought experiment will intuitively suggest that this crushes all incentive for a 'rational' human being, to reduce water consumption. In fact, the properties in question will consume a lot more than what they are paying for, leave alone feeling responsible and cutting back. That, on the upstream, hinders efforts at reducing energy use. This situation prevails, by and large, in 2014, at the time of writing, though there are some pilot projects in Oslo for instance to install water meters, as gathered from Per Kristiansen and Lars Hem. Also gathered from this report was the fact that the Norwegian Government, since the mid-1990s has been urging utilities to increase the proportion of groundwater as drinking water supplies so as to reduce costs and the risk to public health contamination. Also to be noted is the fact that groundwater usually being of better quality than surface water, the energy required for treating it would be relatively lower.

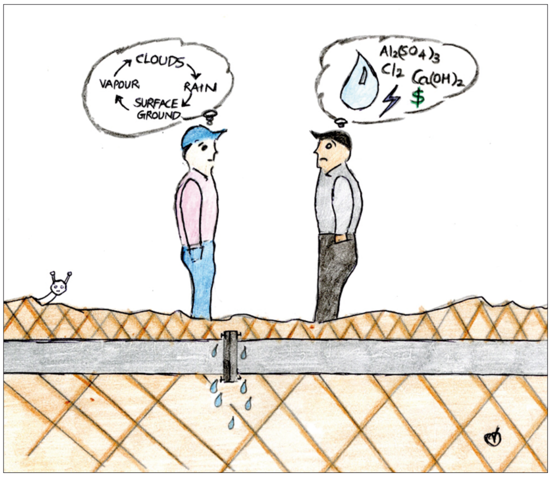

Figure 5. *Leakage implies loss of energy consumed on the upstream to produce the chemicals used for treatment, and also to treat the water (sourced from Venkatesh (2014)).*

Policies or strategies for that matter, are more often than not, influenced by best practices observed in neighbouring countries (or elsewhere on a continent). If these countries are in a similar state of development (socio-economic and political), like the western-world countries for instance, there is every reason to try to toe the line. Further, if there is a ranking system like the European Green City Index for instance (Venkatesh, 2014), a sense of constructive competition is automatically inculcated. This, needless to say, is very healthy and highly desirable. Sample another of Per Kristiansen's observations (Venkatesh and Ugarelli, 2011) – *'The distribution systems in Oslo, when it comes to performance aspects such as leakage rates, are ranked with the former Soviet bloc countries in Eastern Europe. We would like to move up the ladder and be ranked alongside the best on the continent, such as the systems in Amsterdam (The Netherlands) and Copenhagen (Denmark). I would also point out that water as a resource also has ethical and moral connotations for the people of Norway, and slowly but surely people are coming to appreciate the value of water.'* It goes without saying that reducing leakage implies reduction in per-capita water volumes to be treated both upstream and downstream, and thereby, a drop in the per-capita energy consumption values (Venkatesh, 2012; also refer Figure 5). Refer back to the observation made by Haley et al. (2012), that water conservation (reduction in leakage is one way to do that) is an effective mitigation approach.

Magnus Olsen, also Chief Engineer at Oslo VAV, like Lars Hem, tells the authors that focus on energy efficiency issues at the utility has been quite sporadic; owing to the absence of a robust energy management programme in the past. On date, though, the utility has employed key personnel with knowhow of energy savings and an energy management program is now in place. This programme includes, inter alia, a set of indicators to track improvements in energy efficiency. Responding to Q.5 (Table 1), Olsen says that Oslo VAV does not account for the energy consumption related to water use in households and industries; the focus stays on the production and transport of the potable water and the transport and treatment of wastewater only. When quizzed if the 'abundance problem' (of green and clean energy and raw water) comes in the way of design and implementation of projects targeted at improving energy efficiency, he responds in the affirmative and blames the low energy prices that prevail in the country, for the same. Talking about top-down pressure, Olsen informs that the municipality of Oslo has declared that the city will be oil-free by year-2020. Energy efficiency subsidies and taxes levied on gasoline/diesel/oil/electricity, hold enough promise, in his opinion, as far as the march towards energy-efficient water-supply and sewage handling systems are concerned. It is apt to point out here that the biogas from one of the two wastewater treatment plants in the city is refined into biomethane and sold to the public transport system (Venkatesh and Elmi, 2013; Elmi and Venkatesh, 2015). Whether economic policy-instruments like taxes (sticks) and subsidies (carrots) are really effective in improving energy efficiency remains to be seen, in the medium-term.

In Hofshagen (2012), Norsk Vann – the association of water and wastewater utilities in Norway – contends that there is a lot of potential for energy neutrality within the sector, by way of both improvements in energy efficiency (and thereby reduction in energy usage) and the generation of renewable energy within the systems at the same time. Norsk Vann estimates that over 500 GWh of energy can be recovered from effluent wastewater from wastewater treatment plants in the country, by installing heat pumps; over 500 GWh from biogas, and at least 200 GWh by installing microturbines to convert pressure energy of flowing water to electricity. At the same time, the association sees a possible reduction of 20 % in the use of electricity in the water and sanitation systems in Norway. It is worth noting at this juncture that ENOVA SF – a part of the Ministry of Oil and Energy, Government of Norway – supports promising initiatives in energy efficiency improvement (or reduction in energy consumption in other words), by providing grants for the same. Considering that these are grants and not loans (Jorge, 2014), should provide a great impetus to utilities to be innovative and progressive in their march towards greater energy-efficiency and perhaps even energy neutrality.

A Norwegian resident of Trondheim, who was the first to purchase a copy of the book – Water for All and other poems (Venkatesh, 2015), in an e-mail dated 29th January 2015, had this to say to the author *'I am happy to contribute (to the cause of clean drinking water supply in India.) It is an important cause. We are spoiled in Norway with always having access to excessive amounts of clean water.'* Just an indication of the fact that some, if not all, Norwegians would surely be aware of habits which need to be changed. The survey of water consumers elicited 27 responses from around the country. The sample set, it must be admitted at the outset, is not large enough to perform statistical analysis with. Yet, in the time-frame that was available for carrying out this exercise, the authors would like to feel that a reasonably-believable analysis could still be performed.

Conclusions

In this paper the authors set out to present a brief outlook of the water-energy nexus in urban water utilities in Norway. A brief literature review was carried out to find out the extent of research carried out (and published) over the years, on topics related to the use of energy in urban water utilities. The initial intention was to elicit several responses from personnel in water utilities around the country, to a set of common questions pertaining to energy efficiency. The response rate was quite poor. However, it can be said that enough was gleaned to obtain a general outlook of how the use of energy in urban water systems is perceived in Norway. While the abundance of water and clean hydropower may seem like a deterrent to setting in motion energy-efficiency improvement projects, a closer look reveals that this is not necessarily perceived as a deterrent by those who have realised that it is imperative to factor in 'sustainability' into operations, no matter how abundant or scarce resources at one's disposal are. While Oslo, reportedly, has been motivated by the European Green City Index (indirectly thereby by Copenhagen, Amsterdam, etc.) and Norway has taken a leaf out of Sweden's book as referred to in the article, these are instances of western-world countries influencing development and sustainability-thinking among themselves. However, one cannot compare apples with oranges; and thereby what has happened, is happening and will happen in Norway, when it comes to energy efficiency in water utilities, may not necessarily qualify as a 'blueprint' for developments in the developing world for instance. Improving energy efficiency is not merely an economic-environmental-technological exercise, but is impacted (adversely or positively) by well-entrenched social mores and behavioural patterns. This is where 'sustainability thinking' is imperative; and this is why each case (community, city or country) would have to be handled differently.

However, the response rate to the questionnaire despatched to water consumers in Norway, was relatively more encouraging, and enabled the authors to obtain some kind of an understanding – incomplete nevertheless – of what the ordinary Norwegian water (and energy) consumer thinks. A combination of a top-down and a bottom-up progress in understanding the water-energy nexus and implementing policies to improve energy efficiency (and thereby saving and availability for other applications), and energy generation in urban water utilities, is the best situation that could prevail. Norway, despite (and in addition to) being blessed with abundant water resources and clean energy seems to be aware of the imperativeness to work towards a better and a more desirable water-energy nexus in the years to come. Willingness to experiment and implement on the part of the government, and willingness to pay and support on the part of the consumers, working together, in the backdrop of the aforesaid abundance, presents the most perfect test-bed one could imagine, to set the ball rolling.

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