

Rainwater harvesting: environmentally beneficial for the UK?

C. M. Way, D. B. Martinson, S. E. Heslop and R. S. Cooke

ABSTRACT

Rainwater harvesting (RWH) feels right from a long-term sustainability perspective. Short-cutting the hydrological cycle seems to make logical sense from an environmental stance, and the technique is being driven into new buildings in the United Kingdom (UK) through building rating systems which are in turn pushed by government policy. However, little work has been done to assess its environmental credentials from a whole life perspective. Controversially, those studies that have been done have found that RWH systems tend to have greater environmental impacts than mains supply infrastructure. This work seeks to investigate the latest studies, and provide a way forward in the debate.

Key words | lifecycle assessment, rainwater harvesting

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INTRODUCTION

The underlying motivation for the use of rainwater harvesting (RWH) systems in the United Kingdom (UK) stems from water stress. Although commonly considered a 'rainy' country, its water resources are under stress from a combination of factors (EA 2008):

- Population growth leading to growth in overall water demand
- Increasing per person water demand (due in part to decreasing household sizes)
- Population distribution and internal migration into areas with pressured water resources and distribution infrastructure
- Increasing seasonal weather variability due to climate change straining existing water management facilities (also leading to flooding and surface water management issues)

In response to this, various demand reduction initiatives have been taken, and in particular the building industry has come under pressure to facilitate lower

water use in buildings through specification of more efficient fixtures and alternative systems. This is largely being driven by legislation and changes to the Building Regulations (HM Government 2002, 2010). In the UK all new houses must be rated under the Code for Sustainable Homes (CLG 2008). This is a national standard for the sustainable design and construction of new homes. Non-domestic buildings are rated using the Building Research Establishment Environmental Assessment Method (BREEAM 2009) although it is not currently mandatory. Within these rating systems the water component focuses on reducing per-person demand based on a range of assumptions about occupants' water use. To achieve higher level ratings (Code levels 5 and 6, or BREEAM 'Excellent'), the required reductions in potable water use cannot sensibly be achieved through water efficiency alone without drastic lifestyle change. In addition a recent study showed that a number of technical water savings measures may be ineffective in tackling water shortages as they may

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be easily overcome or simply removed in favour of more desirable appliances (AECB 2009).

This has all led to increasing interest in the use of alternative sources of water for lower grade uses such as toilet flushing and irrigation. With its relatively simple system design and ease of understanding, rainwater harvesting (RWH) has proved a popular option. In response, the UK market for RWH has grown rapidly, from around £1 M to £10 M in the past 7 years (Johnen 2010). It is also one of the few technologies that can reduce consumption of mains water with a low impact on the lifestyle of the building's occupants.

Alongside this, the UK has an ever pressing carbon agenda. The Government has various targets to reduce carbon emissions (HM Government 2009), and as the deadlines approach there is increasing urgency to seek 'low carbon solutions' in all aspects of current practice. RWH has become intrinsically connected with the idea of a 'low carbon' or 'green' building, and there is work being done on how best policy can support its wider implementation (Partzsch 2009).

However, after an initial period of enthusiasm, there is now reflection going on amongst some stakeholders, and the technique is starting to be questioned. Not regarding technical system performance, or captured water quality as it has in the past (Mustow *et al.* 1997; Fewkes 1999; Leggett *et al.* 2001), but to fundamentally question the environmental benefit, given the wide, safe and reliable coverage of the 'mains' water supply infrastructure in the UK. The most notable work is that supported by the Environment Agency (Reffold *et al.* 2008; Clarke *et al.* 2009; Parkes *et al.* 2010). All of these studies showed rainwater harvesting to have a larger carbon footprint (and by implication, worse environmental impact) than the business-as-usual case of connecting to the mains network. This is somewhat controversial

given the current momentum behind the popularity of RWH. There is also a certain shock factor that a technology long associated with environmental benefit, may actually be detrimental in terms of carbon. That it was designed to save water not carbon is often overlooked.

In terms of its water saving effects, Coombes (2002) has shown that widespread adoption of domestic-level rainwater harvesting in the Australia can reduce water demand in a catchment by a significant amount. Some early-stage monte-carlo simulations of medium and high-density housing under South-Coastal rainfall conditions carried out at the University of Portsmouth, indicate similar potential savings may be achievable in the UK context.

BASIS FOR COMPARISONS

In trying to structure these arguments for and against RWH in terms of its environmental impact, there are several approaches that can be taken. Commonly the technique is compared with the business as usual case of the mains water supply infrastructure. This puts RWH immediately at a disadvantage as the comparison is then made of the CAPEX and OPEX of RWH against just the OPEX of the mains. A fairer assessment would be to consider RWH as a technology not to replace a portion of the mains supply, but as an alternative to augmentation, that is, delaying or eliminating the need to enlarge the traditional supply with approaches such as reservoir construction or desalination.

For reference Table 1 outlines the key work used as the basis for this study.

This is an emerging field and little has been done in terms of whole-life assessment of RWH systems in the UK context. This means that by necessity assumptions are being

Table 1 | Comparison of reference sources

Reference	Catchment area/ m ²	Building population	Mains supply energy/ kWh/m ³	Pumping energy/ kWh/m ³	Tank information		
					size/ m ³	based on	material
Parkes <i>et al.</i> (2010)a	45	3 people	0.56 - UK	1.5 for direct feed 1 for header tank	1.5	5% rule	PE
Parkes <i>et al.</i> (2010)b	60	4 people	0.56 - UK		2	5% rule	PE
Thornton (2008)	3100	2630 pupils (inc 30 staff)	0.56 - UK	0.4	27	-	GRP
Reffold <i>et al.</i> (2008)	-	36 people	0.56 - UK	3	1.95	-	MDPE
Hallmann (2003)	220	3 people	0.1 - Melbourne	0.6	2.25	-	LLDPE
Crettaz (1999)	100	2 x 4 person family	0.35 - Switzerland	0.09	10	16 days	PE

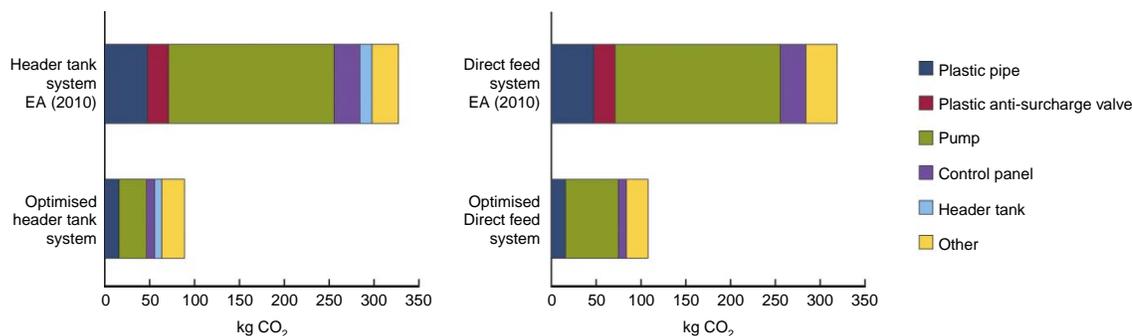


Figure 1 | Optimisation of installed component embodied CO₂. Subscribers to the online version of *Water Science and Technology: Water Supply* can access the colour version of this figure from <http://www.iwaponline.com/ws>.

made with little data to support them. These coarse system assumptions are then being used in otherwise well thought out and rigorous LCA based work.

Similarly, with the work which has been done in this area, care has to be taken over what the original brief was. Specifically the latest work done by the Environment Agency (Parkes *et al.* 2010) is looking at scenarios based on current practice and the application of current British Standards (BSI 2009). It is looking at existing system configurations and design, with sensitivity analyses being done on various scenarios (e.g. of demand variation), but not of highly influential design variables such as pumping energy requirement. They are not trying to be design guides,

and this has perpetuated the gaps in analysis of system configurations, pump sizing, material selection and so on.

MODELLING

In order to start filling this gap in analysis, an optimal scenario was modelled to ascertain how a best practice solution might perform. Components other than the tank were optimised to reduce their carbon emissions, based on emerging industry best practice. Then a possible lower range of pumping energy was investigated using information from new pumps on the market and by better matching size

Table 2 | Explanation of assumption changes from EA 2010 report

Non-tank embodied emissions	Optimised pumping and plumbing were used. Only the header tank system was considered in this modelling as it has the lowest pumping requirement and the consistent needs are amenable to rational pump design. Figures from emerging household technology (eg Rain Director management system, RD 2010) were scaled up by building water use	Household system: 90 kg CO ₂ e School system: 2,000 kg CO ₂ e
Tank embodied emissions	Taken to be the mean of the values presented in the EA report. This is acknowledged to be a simplification, however an analysis of 50 PE tanks from three manufacturers has shown that economies of scale are consistently in the order of 0.9, and the limited volume range available means that storage requirements above 5,000 L must be met by multiple tanks. The value used is also contained within a large scatter of data which dwarfs the potential scale economies	125 kg CO ₂ e/m ³
Pumping energy	Varied according the range of values found in the literature	0.1, 0.2, 0.5 kWh/m ³
Alternative water sources	Two cases of business as usual and the expected energy requirements from Beckton desalination were modelled, plus an allowance for pumping	BAU: 0.3 kg CO ₂ /m ³ Beckton: 2 kg CO ₂ /m ³

and load. Tank sizing was explored using only polyethylene (PE) tanks, as previous work has shown that GRP and concrete versions are generally more impactful from an environmental perspective. Finally the mains emissions were varied to simulate the range between current and potential future practice for water supply.

1. Optimising rainwater harvesting for emissions reduction—how good can it be?

Taking as starting point the latest work by the Environment Agency (Parkes *et al.* 2010), the systems

modelled in the report were optimised to reduce the installed embodied CO₂ as far as possible. The scenario of a domestic system for a 3 bedroom home was used, and both direct feed and header tank options were analysed (Figure 1).

This showed that the emissions associated with the non-tank components could be reduced by 66% in the case of a direct feed system, and by 78% with a header tank configuration. This was achieved through rationalising pipe layouts, matching pump specification to load, and selecting

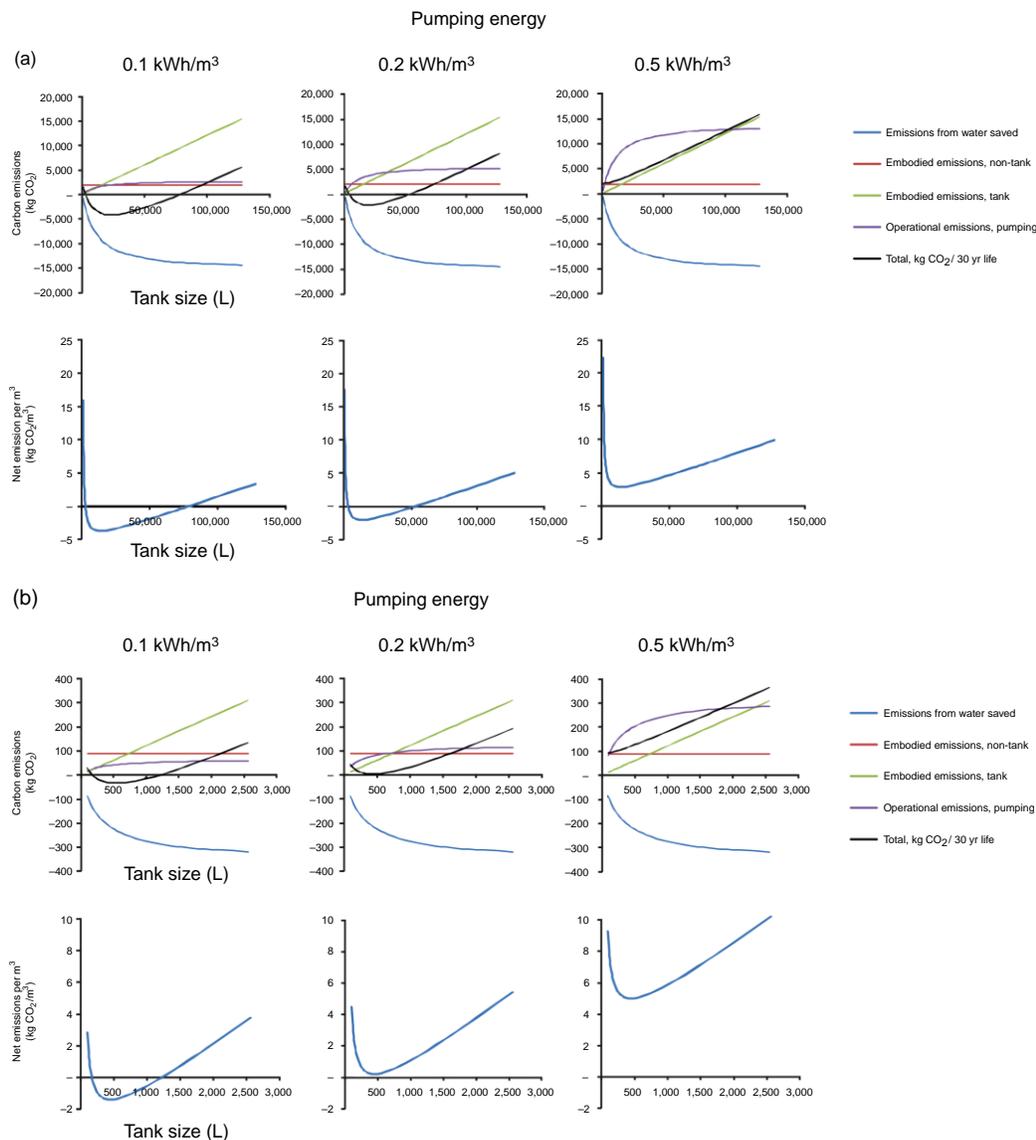


Figure 2 | (a) School Roof size 3.173 m², occupancy: 585 pupils, non-potable water use: 8.2 lcd, 5% rule capacity ≈ 90,000 l, specific net emissions savings optimum ≈ 16,000 l
(b) Household Roof size: 45 m², occupancy: 3 persons, non-potable water use: 51 lcd, 5% rule capacity ≈ 1,500 l, specific net emissions optimum ≈ 500 l. Subscribers to the online version of *Water Science and Technology: Water Supply* can access the colour version of this figure from <http://www.iwaponline.com/ws>.

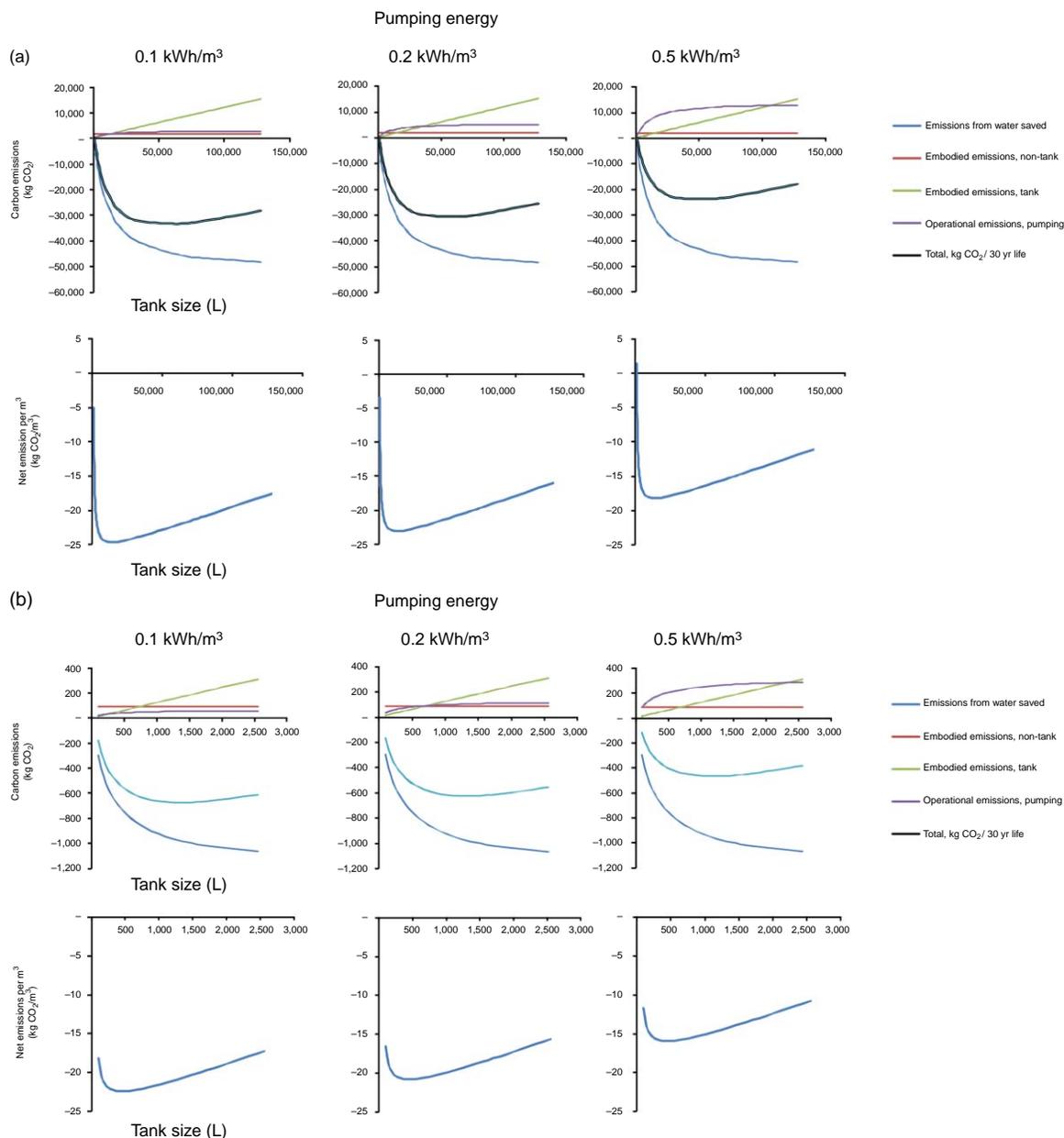


Figure 3 | (a) School roof size 3,173 m², occupancy: 585 pupils, non-potable water use: 8.2 lcd, 5% rule capacity ≈ 90,000 l, specific net emissions savings optimum ≈ 16,000 l
 (b) Household roof size: 45 m², occupancy: 3 persons, non-potable water use: 51 lcd, 5% rule capacity ≈ 1,500 l, /m³ specific net emissions optimum ≈ 500l. Subscribers to the online version of *Water Science and Technology: Water Supply* can access the colour version of this figure from <http://www.iwaponline.com/ws>.

new lightweight pumps and associated technologies. A surprising outcome from the EA report is that non-tank embodied CO₂ forms a large part of the total embodied CO₂, indeed when a small polyethylene tank is used, it can account for over 80% of the total embodied CO₂. In a domestic setting this carbon was shown to completely offset the carbon savings from water conservation.

To investigate the sensitivity of the cradle to site emissions to design variables, the design assumptions covered by the EA report (Parkes *et al.* 2010) were altered for the cases of a house and a school. The changes in assumptions are shown in Table 2.

The climate considered was the 'medium' rainfall scenario used in the EA report (890 mm/yr), yields

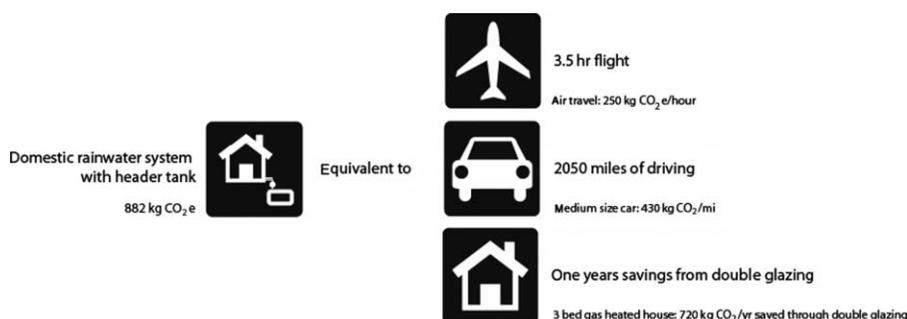


Figure 4 | Comparison of absolute impacts

were calculated using the formula developed by Fewkes & Warm (2000) and for comparability the non potable demands were also those used in the EA report (Parkes *et al.* 2010).

Results reported in the graphs (Figure 2) show lines separated into emissions saved through water saving, embodied emissions for the tank and non-tank components, and the operational emissions. A line representing the cumulative emissions (ie total carbon generated or saved) is indicated by the thicker 'Total' line. For each scenario a specific kgCO₂ per m³ was also generated over a 30 yr life.

A clear optimum tank capacity emerges either on total CO₂ saved or on CO₂ saved per cubic metre delivered. This optimum is not sensitive to pumping energy (for reference the capacity suggested by the industry rule of thumb of sizing tanks based on the smaller of 5% of the yield or demand is also shown). The height of the optimum shows the best case which will give the greatest carbon savings when pumping energy is low and alternative emissions are high, or the least bad case when pumping energy is high and other alternatives have low emissions. The potential for carbon saving is highly sensitive to pumping energy, with an increase of 0.3 kWh/m³ determining whether the system modelled is carbon negative or carbon positive at the optima.

2. Rainwater harvesting vs. other water reduction and augmentation measures—how bad do things have to get before RWH is worth it?

This analysis compares RWH to the desalinated water supply from a new Thames Water facility at Beckton, UK to compare against a worst-case scenario. Currently state-of-the art seawater desalination requires 3–4 kW/m³. A new plant being built at Beckton, near London will use reverse osmosis to desalinate brackish water from the ebb

tide in the Thames estuary. Estimates of its energy use vary; however, it is likely to need in the order of 2 kWh/m³ before distribution (Pilkington 2010).

In this case, due to the very favourable emissions saving through water saving, it is difficult for RWH not to be a more carbon-beneficial option to a desalinated supply. As figure 3 illustrates, a clear optimum tank capacity emerges either on total CO₂ saved or on CO₂ saved per cubic metre delivered, which is not sensitive to assumptions of how energy intensive alternative supplies of water may be.

CONCLUSIONS

Water and energy are intrinsically linked. Energy is effectively used to 'make' water through treatment works, and then transport it to our homes for direct use and heating. Carbon is a key factor in current political and environmental discussions, and it is a convenient indicator in a sound-bite world, but caution must be used that it does not dominate discussions to the detriment of other key issues. Fundamentally there is now a drive to reduce water stress (both scarcity and flood risk) and carbon stress (through emissions reduction). The important question is how and to what extent do RWH systems influence these two aspects? This work has found that by optimising systems appropriately, RWH can be of carbon 'benefit' although with current practice it is not a foregone conclusion, and indeed it is likely to perform badly.

At this point it is interesting to note the real magnitude of these findings. From a broader viewpoint, the absolute impacts aren't very significant. Even an un-optimised system, currently available, has lifetime (30 year) emissions equivalent to a 3.5 hr aeroplane flight (Figure 4).

This work has also highlighted the persistent need for increased quantity and quality of data. This will allow deeper analysis and enable studies to consider, for example, the disposal or the end of life phase, an area few reports have included.

Finally, commonly accepted notions of design should be challenged. Many aspects of current practice make RWH not beneficial from an environmental perspective, but they can be changed. For example casing a GRP tank in concrete is clearly nonsense from an environmental impact perspective when alternatives are available. Suppliers have been known to provide the same pump for direct feed or header tank systems, purely for reasons of limited stock space in their warehouse, resulting in poorly matched pumps with the associated negative effect on the whole systems carbon emissions. Rainwater tanks have previously been identified as being frequently oversized (Roebuck & Ashley 2006; Ward *et al.* 2008) and the persistence of sizing capacity based on the '5%' and '18 day rule' needs to be reviewed.

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