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# A streamlined sustainability assessment tool for improved decision-making in the urban water industry

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## ABSTRACT

Water supply is a key consideration in sustainable urban planning. Recycling may increase the expense and energy consumption of supply systems, raising optimisation questions. Ideally, detailed quantitative sustainability assessments are undertaken during the planning stage in order to inform the decision-making process. In reality, however, the significant time and cost associated with undertaking such detailed environmental and economic assessments is often cited as a barrier to wider implementation of these key decision-support tools, particularly for decisions made at the local or regional government level. In an attempt to counter this barrier of complexity, four water service providers in Melbourne (Australia) funded the development of a publicly available streamlined Environmental Sustainability Assessment Tool (ESAT). The tool is aimed at a wide range of decision-makers to assist them in broadening the type and number of water servicing options that can be considered for greenfield or backlog developments. ESAT consists of a simple user interface and draws upon life cycle inventory data to allow for rapid estimation of the environmental and economic performance of different water servicing scenarios. Scenario options can then be further prioritised by means of an interactive multicriteria analysis. The intent of this paper is to identify the key issues to be considered in a streamlined sustainability assessment tool for the urban water industry and to demonstrate the feasibility of generating accurate life cycle assessments (LCAs) and life cycle costings (LCCs) using such a tool. We use a real-life case study consisting of three separate scenarios for a planned urban development to show that this kind of tool can emulate LCA and LCC outcomes obtained by more detailed studies. We hope this kind of approach will support 'sustainability thinking' early on in the decision-making process, thereby encouraging more sustainable water and sewerage infrastructure solutions.

## Keywords

Sustainable water management; life cycle assessment; life cycle costing; streamlined sustainability assessment tool; multicriteria analysis; recycled water

# INTRODUCTION

There is an increasing recognition of the need to improve the sustainability of our cities. In particular, there is ongoing interest from both industry and government bodies in meeting specific water service provision objectives at minimal environmental and economic cost. Water is often at the forefront of urban sustainability considerations, since it frequently constitutes a large fraction of all material flows through urban regions (Decker et al. 2000). Urban water service provision is most commonly achieved by centralised mechanisms, involving large-scale water and wastewater treatment facilities and distribution networks. Population pressure continues to increase the demand for water and the production of wastes, while climate change has the potential to further reduce water availability from conventional sources (Cohen 2006). As a consequence, innovative approaches to urban water supply such as blackwater recycling, greywater reuse, rainwater tanks, stormwater harvesting, dual pipe systems and desalination have received increased attention.

Sustainability assessment tools such as life cycle assessment (LCA), life cycle costing (LCC) and multicriteria analysis (MCA) allow for more holistic assessments of infrastructure alternatives, allowing decision-makers to consider both the economic and environmental consequences associated with a given water service delivery strategy. Due to their holistic and comprehensive scope, these techniques are also recognised as being both time- and resource-intensive and require a high degree of expert knowledge. Unfortunately, these factors are often cited as a barrier for the more widespread application of approaches like LCA in the industry and policy-making sectors (Bala et al. 2010). Consequently, there has been significant recent interest across a number of industrial sectors in the development of so-called ‘streamlined’ approaches and tools to reduce the burden of these more detailed assessment processes.

The water sector has been at the forefront of the development and application of LCA, with some of the first reported LCA studies in this area conducted prior to the publication of the original ISO 14040 Standard in 1997 (Emmerson et al. 1995, Roeleveld et al. 1997). Australia has played a significant role in these developments (Peters G 2009) and an extensive literature is now available on LCA studies in the area of water cycle management both internationally and in Australia (Friedrich et al. 2007). The most comprehensive of this work by Lundie *et al.* (2004) covered the total operations of Australia’s largest water utility (Sydney Water), including bulk water supplies, water filtration plants, reticulation and wastewater treatment. Another detailed study by Friedrich *et al.* (2009) included both water supply and wastewater treatment services for a South African municipality. Other studies have addressed specific aspects of either wastewater systems (Beavis and Lundie 2002, Emmerson et al. 1995, Lim and Park 2009, Lundin et al. 2000, Pasqualin et al. 2009, Tillman et al. 1998), different biosolids management options (Dennison et al. 1998, Peters G. M. and Rowley 2009, Tangsubkul et al. 2005) or potable water supply systems (Crettaz et al. 1999, Friedrich 2001, Landu and Brent 2006). Additional studies investigating both environmental and economic impacts of different aspects of the urban water cycle also exist (Hoibye et al. 2008, Lim et al. 2008, Nogueira et al. 2007, Sharma A. K. et al. 2009). All of the abovementioned research has been carried out using the traditional and more detailed methodologies, and published reports detailing the application of ‘streamlined’ sustainability assessment tools in the water industry are rare (Friedrich et al. 2007).

Simplified or ‘streamlined’ sustainability assessment tools have the capacity to provide similar results to more detailed assessment approached but at lower cost and with reduced requirements for operator time and expertise (Bala et al. 2010, Hochschorner and Finnveden 2003). This is particularly relevant in the context of industry and policy-making sectors, where decisions with potentially large environmental and economic consequences are often made with limited time and financial resources and where the decision-making process often cannot wait for the results of full LCAs (Bala et al. 2010). In the context of the urban water sector, the development and application of a streamlined Environmental Sustainability Assessment Tool (ESAT) would enable assessment of the relative sustainability of alternative water and sewage servicing (infrastructure) options and, therefore, better position industry decision-makers to ultimately select the most environmentally and economically sustainable approach.

This paper demonstrates the feasibility of creating such a tool. ESAT was developed by researchers at the University of New South Wales in partnership with the Smart Water Fund and can be downloaded from the Smart Water homepage (Schulz and Peters 2008a). ESAT enables quantitative LCA and LCC to be carried out in a user-friendly Microsoft Excel® environment. Local water service providers have indicated a desire to be able to quantify financial and environmental performance indicators and then contrast and prioritise decision options by means of an MCA. ESAT facilitates this by allowing the user to measure one economic and five environmental performance indicators, with an inbuilt MCA utility providing a mechanism for weighing and combining the results from the individual indicators. Our model is intended to support and encourage 'sustainability' or 'life cycle thinking' as described by Elshof (2007) by identifying and measuring key variables to inform and promote sustainable decision-making in the area of water and sewerage infrastructure provision and asset management. In this paper, some of the capabilities of ESAT are demonstrated through a case study assessment of the environmental and economic sustainability of three different water servicing options for Kalkallo, a greenfield development area north west of Melbourne, Australia. The robustness of the results from this simplified tool are then compared with the results of a detailed LCA and LCC undertaken by an independent group of researchers during 2005 and 2006.

## METHOD

Here we describe the general principles for construction of a simplified too for sustainability assessment of water systems in any city, with Melbourne as an example. The key to accelerating the application of 'life cycle thinking' in of water service provision is to simplify the creation of complex life cycle inventories for alternative servicing options. To do this requires a balance to be struck between the future extent of software tool application (i.e. tool universality) and the need for a simple user interface. The dialogue in which we engaged water industry representatives taught us that a simplified tool should make a range of information available which is broader in scope than what water engineers are likely to encounter during a 'normal' week, without attempting to match the level of comprehensiveness (data input types, modelling methods or environmental performance indicators) offered by commercial LCA and LCC software packages such as GaBi (PE International 2008) or SimaPro (PRe Consultants 2008). In the following sections, the main types of information and adjustable design features of needed in such a simplified tool are described. For more detail on the features, input variables required, relevant LCI data and modelling principles of ESAT please refer to the online manual (Schulz and Peters 2008b).

## End-use Water Balance

An end-use water balance is an essential first step in the planning of any water infrastructure. In order to accurately estimate the levels of water demand and wastewater generation for a particular development, the user should be able to specify the number of households / buildings in the development, the number of people per household / building, an additional water demand for non-household use (i.e. municipal irrigation or industrial / commercial use), the expected level of efficiency of various household appliances (e.g. washing machines, shower heads, etc. ESAT assumes an initial individual water demand of 207 litres/person/day (L/p/d) which represents the consolidated average daily residential water consumption for Melbourne (WSAA 2006). .Currently, the user can select the location of the proposed urban development from five sub-regions of Greater Melbourne. This function draws on a 30-year daily time step historical rainfall record for each sub-region to enable spatially relevant estimations of rainwater and stormwater runoff to be made. Prior research has shown that rainfall records of this length and interval are appropriate for facilitating accurate simulations of future rainfall (Mitchell V. G. et al. 2008). For further details on the assumptions incorporated into ESAT with regards to the end-use water balance, rainwater and stormwater modelling calculations, the reader is referred to the online ESAT manual (Schulz and Peters 2008b).

## Reticulation Options

Three different sewage reticulation systems may be of interest in a simplified tool: conventional gravity systems, low pressure sewage systems and vacuum systems. Of course the topography and scale of urban developments effects their environmental impacts and costs, so further input fields are relevant to allow the user to perform detailed modelling of different parts of the reticulation system, including the selection of: different piping materials, diameters and lengths; the installation of a number of pumping stations combined with rising mains and gravity mains; and the incorporation of maintenance holes. Within the reticulation modelling component of ESAT, particular attention was given to the pumping energy calculations. This was because earlier work had shown that the environmental impacts associated with pumping energy requirements are significant in situations where there is a heavy reliance on coal-fired electricity generation such as Australia (Lundie et al. 2005). ESAT calculates the energy requirements for pumping wastewater through the rising mains based on the approach of Coulson and Richardson (1985). It is also possible to model the connection to an existing sewer network and to enter the respective energy consumption involved. Again, further details on reticulation assumption and pumping energy calculations can be found in the online ESAT manual (Schulz and Peters 2008b).

## Wastewater Treatment Options

Many different treatment technologies might be considered in a simplified sustainability assessment tool, som of which are more relevant at particular geographic scales. We think the analyst also needs the option of including industrial or commercial wastewater inputs into the normal domestic wastewater stream. This option may be appropriate if the planned development includes some commercial facilities that produce wastewater, or if nearby existing businesses want to connect to the wastewater treatment system of the proposed development. ESAT allows the user some degree of flexibility in terms of how wastewater is treated. A household-scale greywater treatment system and eight different household- and neighbourhood-scale blackwater treatment systems with different treatment technology configurations may be selected. The respective life cycle inventory (LCI) data was obtained directly from manufacturers or from the relevant literature; for details see Schulz and Peters (2008b). Their environmental and economic performance can be compared to that of a conventional centralised sewage treatment plant (STP) if desired. ESAT also caters for modelling the reuse of treated wastewater in the event that there is a demand for recycled water within the development. If treatment at a conventional STP is required, the location of the development determines whether the sewerage goes to Melbourne’s Eastern or Western Treatment Plant (Melbourne Water 2006a, b), both of which have different operating conditions.

## Water Supply Options

Six common water supply options are noteworthy among the urban water LCA studies mentioned earlier in this article: surface water; groundwater; seawater desalination rainwater tanks, stormwater and recycled water supplies. In addition to these water supply choices, questions of scale may play a role and necessitate the software user’s detailed definition, for example, the choice of rainwater tank size. Depending on this, the connected roof area, the chosen rainwater end-uses and the modelled rainfall for the selected region, ESAT calculates the relative contribution to the household water balance made by rainwater yield. Further details on LCI data and rainwater modelling assumptions can be found in Schulz and Peters (2008b).

In ESAT, stormwater may be treated by two different treatment options: a raingarden; or a surface wetland. The main focus is on the nutrient removal capabilities of both systems. The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) Software (eWater 2005) was used to estimate treatment performance in terms of the key water quality parameters of interest (total suspended solids, total nitrogen and total phosphorous) and the capital and operating expenditures for different sizes of both stormwater treatment systems. Additionally, a stormwater reuse option is available based on the collection of stormwater running off from impervious surfaces around the house. Recycled water for non-potable purposes can be made available to households by connecting to a water recycling plant via a centralised “third pipe” option (also called “dual reticulation scheme”) or from local supplies sourced from some of the decentralised wastewater treatment options. A range of end-uses for the recycled water or stormwater can then be selected. Further details on the assumptions underlying water recycling in ESAT are available elsewhere (Schulz and Peters 2008b).

## Cost Analysis

The industrial partners of the Smart Water Fund wanted any simplified tool to include evaluation of const in a manner that reflects widespread industry practice. ESAT takes into consideration capital expenditure, energy cost related operating expenditure and other operating expenditure (e.g., maintenance, chemicals, etc.) for all water servicing infrastructure items and calculates an LCC expressed as the net present value (NPV) as described in Eq. (1)

$$NPV = C_0 + \sum_{t=1}^{N} \frac{C_t}{(1+r)^t} \qquad (1)$$

where $C_0$ = initial investment, $N$ = total time of the project (assumed 50 years), $t$ = time of the cash flow, $C_t$ = net cash flow and $r$ = adjusted discount rate.

## Life Cycle Impact Indicators

The selection of indicators will necessarily reflect the needs of the urban water industry and the preferences of the environmental managers in the water companies that wish to benefit from using a simplified tool. In our dialogue with industry, we selected those regional and global indicators shown in Table 1. These impact indicators are common among many detailed LCA studies, both within the water field and outside it. In ESAT, the results of these indicator calculations are displayed alongside the environmental impacts resulting from the household water balance as well as the detailed impacts associated with the LCI data such as electricity and materials associated with the scenarios chosen. For the calculation of impact indicator results, the most appropriate available cradle-to-gate LCI data sets were used, e.g. the GHG emissions for one kWh of electricity produced in Victoria. For further details on the presentation of results in ESAT, please refer to the online ESAT manual (Schulz and Peters 2008b).

**Table 1.** Description of the environmental life cycle impact indicators used during this study.

| Impact categories | Units | Description |
|---|---|---|
| Primary energy use | MJ | Includes all fossil energy use associated with the production of materials, generation of electricity and consumption of transport fuels. |
| Greenhouse gas emissions (GHG) | t CO2-eq | Accounts for all GHG emissions linked to the manufacture of water infrastructure, the provision of operating materials including electricity generation and emissions from transport. The IPCC (2007) equivalence factors were applied. |
| Water use | ML H2O | Reflects both the water used during material production or electricity generation as well as the remaining potable water demand. For the first component of the water use, the characterisation method EDIP 97 has been used (Wenzel et al., 1997). |
| Eutrophication potential | kg PO4-eq | The impact indicator called “Nutrients” in ESAT refers to eutrophication potential and describes the nutrients discharge in connection with the full life cycle of the water servicing options included in ESAT. This impact indicator is based on CML (2001) methodology. |
| Physical footprint | Ha | Describes the land area physically occupied by infrastructure necessary for the chosen water service scenario. It follows a simple land use approach as described by Heijungs et al. (1997) and is not to be confused with the “ecological footprint”. |

## ESAT VALIDATION – A CASE STUDY OF THREE SCENARIOS

Kalkallo is a planned greenfield development area for 86,000 people located north of Craigieburn, approximately 30 kilometres north west of Melbourne's City Centre. A total area of 3,062 hectares of predominantly agricultural land will be converted into residential, industrial, commercial and community areas. A detailed LCA and LCC comparing different water and sewerage servicing options for the area was undertaken by another research group during 2005–2006 (Grant and Opray 2005, Sharma A et al. 2005, Sharma A et al. 2006).

In order to critically assess the accuracy of our streamlined tool, three of the scenarios described in the detailed LCA/LCC study are analysed and compared with the results obtained from ESAT. In the first two scenarios—labelled "1A UDM" and "1A WPDM" in the detailed studies—potable water and sewerage services are provided by conventional means. The only difference between these two scenarios is the water demand management assumptions. The usual demand management (UDM) scenario refers to water end-use figures corresponding to a lower standard of water saving appliances than the "White Paper" demand management (WPDM) scenario (DSE 2004), both of which have been calculated using Yarra Valley Water data and the Australian / New Zealand Standard for Water Efficient Products (AS/NZS 2003). Hence, WPDM assumes a reduction in the usual residential water demand in L/p/d from about 223 (UDM) to about 188, or a 15.6% reduction (Sharma A et al. 2005). In the third scenario—"1B.1 WPDM"—the wastewater from residential, commercial, industrial and community sectors is treated at a local STP and returned to the development via a third pipe system for reuse in toilets and outdoor areas across all sectors. An overview of the three scenarios is given in Table 2.

**Table 2**. Description of the investigated water servicing scenario options for the proposed Kalkallo development.

| Scenario | Water supply | Water use | Sewerage system |
|---|---|---|---|
| 1A UDM | • Reticulated, centralised bulk water supply system | • Usual demand management (UDM) | • Reticulated, centralised treatment at Werribee STP |
| 1A WPDM | • Reticulated, centralised bulk water supply system | • Reduced water demand by utilising White Paper demand management (WPDM) | • Reticulated, centralised treatment at Werribee STP |
| 1B.1 WPDM | • Reticulated, centralised bulk water supply system | • Reduced water demand by utilising White Paper demand management (WPDM) | • Decentralised treatment plant at Kalkallo |
|  | • Treated wastewater via third pipe | • Recycled water for toilets and outdoor areas |  |

### Goal And Scope Of The Comparison

The goal of this comparative LCA is to evaluate different water and sewerage servicing options for the Kalkallo development using ESAT and verify the accuracy of these results by comparison with parallel results from a detailed LCA/LCC of the same options. The functional unit was defined as the supply of potable water and water sewerage services to the

Kalkallo development for one year. The system boundary encompassed all processes from the source of potable water to the treatment of wastewater and waste water reuse. For these processes, environmental burdens associated with different materials and energy used were included in both the detailed LCA and in ESAT. The life cycle environmental and economic inventory data was taken from the respective detailed LCA report (Grant and Opray 2005, Sharma A et al. 2005) and LCC report (Sharma A et al. 2006). Greenhouse gas (GHG) emissions, water use, eutrophication potential and LCC are common indicators to both the detailed LCA/LCC and ESAT and were, therefore, considered to be an appropriate basis for comparing the two approaches.

## Life Cycle Inventory Data

### *Household / Building Water Balance*

The residential area consists of 28,695 lots with three people living in each lot; both of these input variables can be entered into ESAT. ESAT assumes a default city-wide average water demand of 207 L/p/d based on Greater Melbourne average data (WSAA 2006). In order to match the assumed 223 L/p/d for the UDM and the 196 L/p/d for the WPDM scenarios at the Kalkallo development (plus an assumed leakage rate of 4%) (Sharma A et al. 2005), appropriate water saving appliances were selected in ESAT. The potable water demand and wastewater generation rates of the commercial, industrial and community areas were taken from the detailed LCA report and were entered into ESAT as an additional “non-household water demand” (UDM: 7,133 ML/a; WPDM: 5,756 ML/a).

**Table 3.** Usual demand management (UDM) scenario water balance for the Kalkallo development area comparing values from the detailed LCA with ESAT-derived values.

| | | ***Sectors*** | | | | |
|---|---|---|---|---|---|---|
| | **Units** | **Residential** | **Commercial** | **Industrial** | **Community** | **TOTAL** |
| **Number of lots** | | 28,695 | 45 | 447 | 5 | |
| **Potable demand** | L/lot/d | 670 | 85,890 | 32,425 | 84,658 | |
| *(detailed LCA)* | ML/a | 7,306 | 1,468 | 5,504 | 161 | **14,439** |
| **Potable demand** *(ESAT)* | ML/a | 7,297 | 1,468 | 5,504 | 161 | **14,430** |
| **Discrepancy potable demand** | % | 0.1* | 0 | 0 | 0 | **0.1** |
| **Wastewater produced** *(detailed LCA)* | ML/a | 5,214 | 1,322 | 4,740 | 144 | **11,420** |
| **Wastewater produced** *(ESAT)* | ML/a | 5,697 | 1,322 | 4,740 | 144 | **11,903** |
| **Discrepancy wastewater** | % | −9.3** | 0 | 0 | 0 | **−4.2** |

** Slight discrepancy in potable demand values due to and inexact match of WPDM values, see above.*

*** Discrepancy due to different proportion of water becoming wastewater, i.e. proportion of residential water demand used for irrigation assumed in ESAT (24.6%) was different to that assumed in the detailed Kalkallo LCA (30.9%).*

In the same way, the amount of wastewater produced in these three sectors is captured in ESAT as an “industrial / commercial wastewater input” (UDM: 6,206 ML/a; WPDM: 4,893 ML/a). The results for the water balance for Kalkallo are shown in Table 4 and Table 5.

The average annual rainfall in the proposed Kalkallo decelopment area is 601 mm. This value is close to the default value of the “central development region” as defined in ESAT, which is based on the Melbourne Regional Office rainfall station which recorded a median yearly average of 610 mm.

### *Potable Water Supply*

In all scenarios it is assumed that the potable water supply comes from a reservoir and undergoes water filtration. The electricity demand for potable water treatment and potable reticulation was estimated to be 0.28 kWh/kL and 415 kWh/ML respectively based on the work of Grant and Opray (2005). These values were used as default values in ESAT.

**Table 4.** White Paper demand management (WPDM) scenario water balance for the Kalkallo development area comparing values from the detailed LCA with ESAT-derived values.

| | | ***Sectors*** | | | | |
|---|---|---|---|---|---|---|
| | **Units** | **Residential** | **Commercial** | **Industrial** | **Community** | **TOTAL** |
| **Number of lots** | | 28,695 | 45 | 447 | 5 | |
| **Total water demand** *(detailed LCA; potable plus reclaimed water)* | L/lot/d | 565 | 68,886 | 26,281 | 67,898 | |
| **Potable demand** *(detailed LCA)* | ML/a | 3,499 | 1,001 | 3,680 | 110 | **8,290** |
| **Reclaimed water use** *(detailed LCA)* | ML/a | 2,432 | 161 | 713 | 18 | **3,324** |
| **Total water demand,** *(ESAT)* | ML/a | 6,144 | 1,162 | 4,393 | 128 | **11,827** |
| **Discrepancy total water demand** | % | −3.6* | 0 | 0 | 0 | **−1.8** |
| **Wastewater** *(detailed LCA)* | ML/a | 4,113 | 1,042 | 3,737 | 114 | **9,006** |
| **Wastewater,** *(ESAT)* | ML/a | 4,544 | 1,042 | 3,737 | 114 | **9,437** |
| **Discrepancy wastewater** | % | −10.5** | 0 | 0 | 0 | **−4.8** |

** Slight discrepancy in potable demand values due to and inexact match of WPDM values, see above.*

*** Discrepancy due to different proportion of water becoming wastewater, i.e. proportion of residential water demand used for irrigation assumed in ESAT (24.6%) was different to that assumed in the detailed Kalkallo LCA (30.9%).*

### *Decentralised Wastewater Treatment*

Scenario 1B.1 WPDM would require the construction of a local STP at the Kalkallo development site. Since the development was in the early planning phase and no detailed infrastructure plans were available at the time of study, the detailed LCA based its assumptions regarding a local wastewater treatment facility on the existing Whittlesea STP and up-scaled the infrastructure to suit the service requirements for the planned Kalkallo development. The Kalkallo STP would be approximately 20 times larger than the Whittlesea STP. The modelling approach taken in ESAT was based on connecting Kalkallo to a centralised STP (scenarios 1A) but also to provide recycled water via a water recycling plant. Considering the large volume of wastewater produced in Kalkallo and the comparatively small volumetric capacity (300 kL/d) of the most suitable neighbourhood-scale decentralised wastewater treatment system incorporated in ESAT, this approach was considered to be most realistic. The wastewater and recycled water treatment processes are modelled from generic technology descriptions and process performance data; for further details please refer to (Grant and Opray 2005, Schulz and Peters 2008b). With regards to the electricity consumption for wastewater and reclaimed wastewater treatment, values of 0.73 and 0.95 kWh/kL respectively were entered into ESAT based on the assumptions of the previous detailed LCA report (Grant and Opray 2005).

### *Reticulation*

The detailed LCA and LCC reports list LCI data for over 20 different pipe diameters and their respective lengths, materials and total construction cost per metre for all reticulation requirements for all scenarios (Sharma A et al. 2005, Sharma A et al. 2006). Because ESAT is designed for use at a reduced level of data complexity, several simplifying assumptions had to be made to allow the more detailed data to be compressed for inclusion in the ESAT platform. To estimate the total pipe material requirements, a length-weighted average cross-sectional area of the detailed reticulation data was calculated to determine an equivalent average pipe diameter and then multiplied by the total length of the reticulation network. Since ESAT only caters for two different pipe materials, uPVC and ductile iron cement lined (DICL) pipes, the pipe materials listed in the detailed LCA report had to be associated with these two pipe material categories. To achieve this, all polyethylene, uPVC and glass reinforced plastic (GRP) pipes were treated as uPVC pipes, and all DICL, mild steel cement lined (MSCL) and vitrified clay pipes (VCP) were treated as DICL pipes. While the physical properties and attributes of some pipe materials are not readily interchangeable with the default uPVC and DICL materials (e.g., GRP and VCP), the lengths of these materials were relatively insignificant in terms of the total reticulation network and the overall consequences of this assumed substitution on the results were considered negligible.

The detailed LCA report assumes an identical electricity demand for supplying 1 ML of potable water to Kalkallo in all modelled scenarios. According to Yarra Valley Water's energy maps, the electricity demand for potable water reticulation is 415 kWh/ML (Grant and Opray 2005). The electricity demand for the reticulated sewer network of 451 kWh/ML was based on the values of Grant and Opray (2005) and was used in ESAT. Because the physical location of a proposed "local / decentralised" Kalkallo STP (scenario 1B.1 WPDM) would not be expected to be significantly different to that of a "centralised" STP (scenarios 1A), it was considered appropriate to adopt the same value for sewerage reticulation electricity demand. In addition to sewerage energy considerations, the electricity demand for supplying recycled water in scenario 1B.1 WPDM also needed to be considered. Since no specific data was available, it was assumed that the source of recycled water supply was similar in both distance and elevation to the potable water supply. The relevant energy requirements for pumping wastewater and recycled water are calculated in ESAT by means of an incorporated formula (Coulson and Richardson 1985, Schulz and Peters 2008b).

To estimate the total construction cost of different pipe connections, the cost data for the various pipe materials and diameters was drawn from the detailed LCC report and used to calculate a total construction cost function in ESAT. In contrast to the pipe material calculations, a length-weighted average diameter was calculated for both uPVC-type and DICL-type pipes and combined with the calculated cost function.

### *Additional Modelling Parameters*

For most water treatment facilities, energy consumption dominates overall environmental performance, particularly when GHG emissions are considered. Therefore, it is necessary to enter specific energy consumption data for all water servicing options when applying ESAT to real-life scenarios. In order to increase ESAT's flexibility to be able to handle as many different circumstances as possible, the user has the option of entering defined energy consumption values for their particular treatment processes. In the detailed LCA study, the water balance model 'Aquacycle' (Mitchell V G 2003) was used to calculate the water balance outcomes for the different scenarios. One assumption in Aquacycle is that there is no stormwater inflow or infiltration into the wastewater reticulation system. Consequently, the relevant input variable in ESAT is set to a default 0%.

The detailed LCA did not include any estimates of material reprocessing or recycling. ESAT, however, has the capacity to take into account that some materials (i.e. steel and polyethylene) are recycled and reprocessed to produce new materials. From an environmental perspective, reprocessing of these materials represents a material and/or energy saving or an environmental credit. For the purposes of this case study, the recycling rates were set to 0% in order to reflect the input variables of the comparative detailed LCA. If available, life spans used for different infrastructure items in the detailed LCA were matched accordingly in ESAT. ESAT also accounts for environmental burdens in relation to transport distances for various materials, i.e. truck and ship transport for materials and pre-installed systems. In the detailed LCA, only transport burdens associated with pipe installation were considered.

Biosolids, a by-product of wastewater treatment, can be applied during agriculture as a substitute for conventional nitrogenous and phosphorous fertilisers. Results from a recent study of various biosolids management systems suggest that for each dry kg of biosolids applied to fields, 0.011 kg of N-fertiliser and 0.037 kg of P-fertiliser can be avoided (Peters G. M. and Rowley 2009). Once again, ESAT has the capacity to incorporate this environmental credit based on biosolids production for each scenario, whereas the detailed LCA did not include any information on biosolids management. To ensure consistency for the purposes of this validation study, biosolids management aspects were also omitted from the comparative assessment in ESAT.

In both the detailed LCC and ESAT relevant cost data included capital expenditure for water supply reservoirs, all reticulation infrastructure as well as wastewater treatment and recycling facilities, operating expenditure separated by annual maintenance costs for different infrastructure items and electricity costs for water and wastewater treatment and pumping. For further information on detailed cost data, references and further assumptions, please refer to the ESAT manual and the detailed LCC report (Schulz and Peters 2008b, Sharma A et al. 2006). Since reticulation is often a large proportion of the LCC of a water supply network and because pipe cost data may vary significantly, the LCC component of ESAT allows the user to enter specific construction cost functions for uPVC and DICL pipes. For the LCC modelling, ESAT assumes an adjusted annual discount rate of 6.5% and an electricity cost of 16c/kWh based on the prior assumptions of the detailed LCC study (Sharma A et al. 2006). An analysis period of 50 years was chosen for LCC modelling in ESAT and it was assumed that both the remaining useful life of all components and the salvage value of any infrastructure after the analysis period were zero. These assumptions reflected those made for the LCC component of Sharma *et al.* (2006).

## RESULTS AND DISCUSSION

Results from the comparative assessment of ESAT outputs versus those from more detailed prior LCA/LCC research for the same development site (Grant and Opray 2005, Sharma A et al. 2005, Sharma A et al. 2006) showed a striking similarity for many indicator categories across the LCA and LCC components. An overall summary of the absolute results is provided in Table 5, with a breakdown of these results for each indicator as a percentage compared with scenario 1A UDM also presented in Fig. 1 to Fig. 4. With both the streamlined and the detailed approaches to LCA and across all indicators, the reduced water demand of scenario 1A WPDM led to a superior environmental performance compared to the base scenario 1A UDM. Scenario 1B.1 WPDM scored better again than scenario 1A WPDM with regards to water use and eutrophication potential but was shown to result in slightly higher GHG emissions due to the higher electricity requirement for treating wastewater to a level suitable for reuse (0.95 kWh/kL) relative to electricity required to produce potable water from a dam (0.28 kWh/kL).

Results from the LCC assessment are presented in both Table 5. and Fig. 4. From a purely economic standpoint, scenario 1A WPDM was the most preferable option followed by scenario 1A UDM. Scenario 1B.1 WPDM was shown to have the highest LCC mainly due to the additional reticulation infrastructure requirements of the third pipe system. Notably, the capital expenditure required for installation of the reticulation network made the biggest single contribution to the total LCC in all scenarios and this trend was reflected in both the outputs of ESAT and also the detailed LCC study.

Fig. 1 to Fig. 4 show the relative environmental and economic performance for each indicator and for all scenarios as a percentage of the base scenario 1A UDM. For all sustainability indicators investigated, the results from the two approaches were shown to be consistent for the purposes of strategic environmental analysis in that the relative environmental and economic performances metrics differed by less than 10%, with the greatest difference being 7.2% for the GHG emissions of scenario 1B.1 WPDM.

Whilst relative differences between measured performance indicators for ESAT and the detailed LCA/LCC study were small, there were some more notable differences in terms of the absolute magnitude of these indicators. In the case of eutrophication potential, for example, the absolute values calculated by ESAT were on average about four times higher than those from the detailed LCA report. The basis for such a large discrepancy in this instance was attributed to the different reference sources having been used for water quality metrics (i.e. biochemical oxygen demand (BOD), total nitrogen (TN) and total phosphorous (TP)) in different kinds of water. The main source of the apparent difference was found to be the much lower TP concentration assumed for treated wastewater and recycled water in the detailed LCA study. Whereas the detailed LCA assumed a TP concentration of 0.5 mg/L for both types of water, ESAT assumed much higher TP levels of 8.8 mg/L and 4 mg/L for treated wastewater and recycled water respectively. Because the reference sources used in the detailed LCA were considered to be either outdated or poorly defined, values for ESAT were drawn from more recent (2005–2006) Melbourne Water Data (Melbourne Water 2006a) since these were considered to provide a more accurate reflection of the true eutrophication potential.

**Table 5.** Summary of absolute ESAT results versus those of the detailed LCA report (Grant and Opray 2005, Sharma A et al. 2005, Sharma A et al. 2006) for the proposed Kalkallo development water servicing scenarios.

| | **Scenario** | **1A UDM** | | **1A WPDM** | | **1B.1 WPDM** | |
|---|---|---|---|---|---|---|---|
| **Indicator** | **Unit** | **ESAT** | **detailed LCA** | **ESAT** | **detailed LCA** | **ESAT** | **detailed LCA** |
| **GHG** | t $CO_2$-eq | 25,086 | 26,290 | 20,293 | 21,520 | 22,376 | 21,560 |
| **Water use** | ML | 14,539 | 14,000 | 11,916 | 11,580 | 8,601 | 8,084 |
| **Eutrophication potential** | kg $PO_4$-eq | 403,508 | 96,570 | 323,714 | 81,050 | 277,173 | 60,790 |
| **LCC** | NPV (M$) | 518 | 526 | 485 | 509 | 604 | 601 |

**Fig. 1.** Greenhouse gas emissions as a percentage of scenario 1A UDM calculated by ESAT versus data of the detailed LCA report (Grant and Opray 2005, Sharma A et al. 2005) for the three proposed Kalkallo development water servicing scenarios.

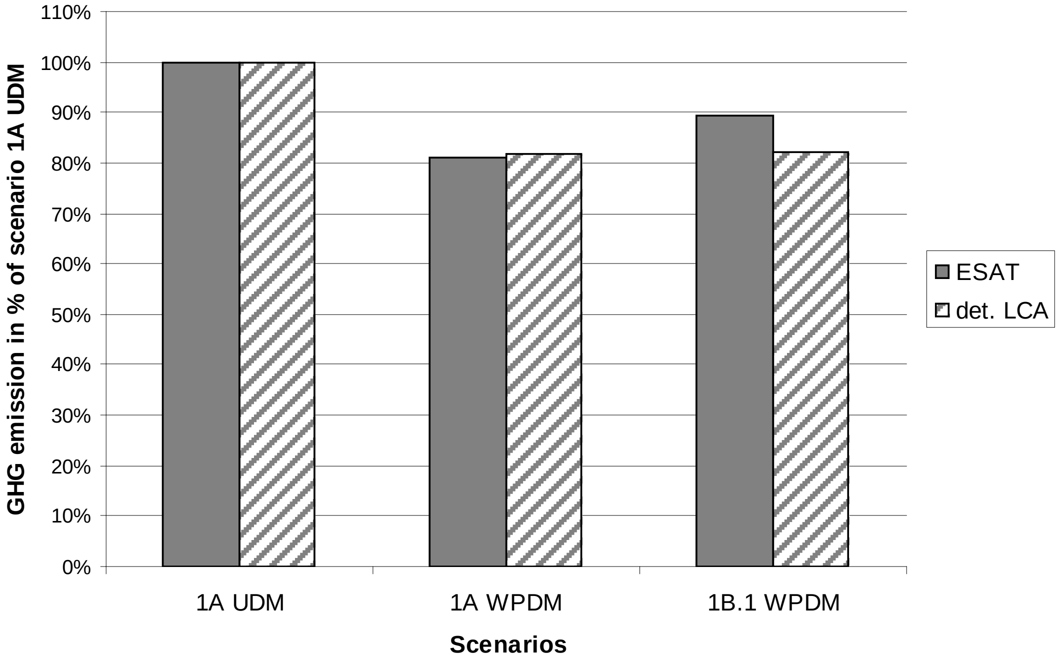


**Fig. 2.** Water use as a percentage of scenario 1A UDM calculated by ESAT versus data of the detailed LCA report (Grant and Opray 2005, Sharma A et al. 2005) for the three proposed Kalkallo development water servicing scenarios.

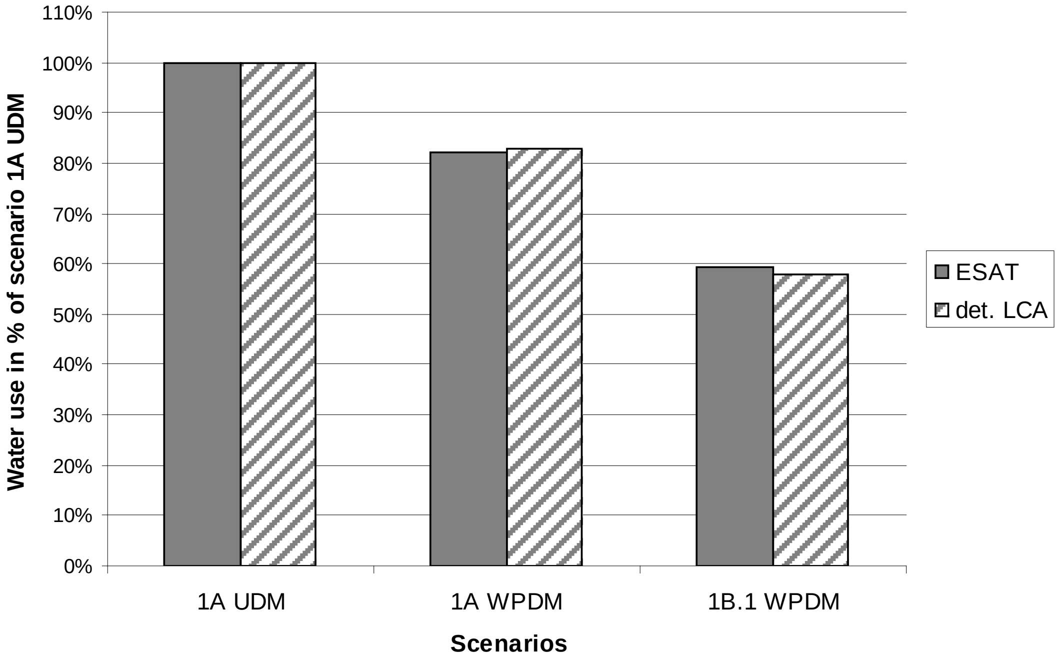
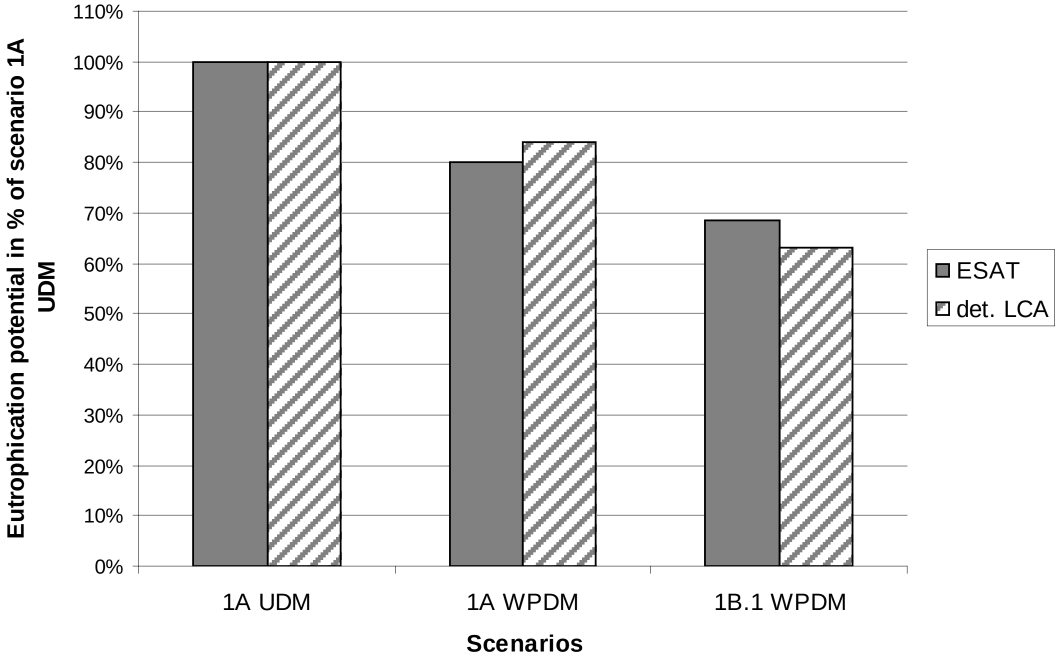


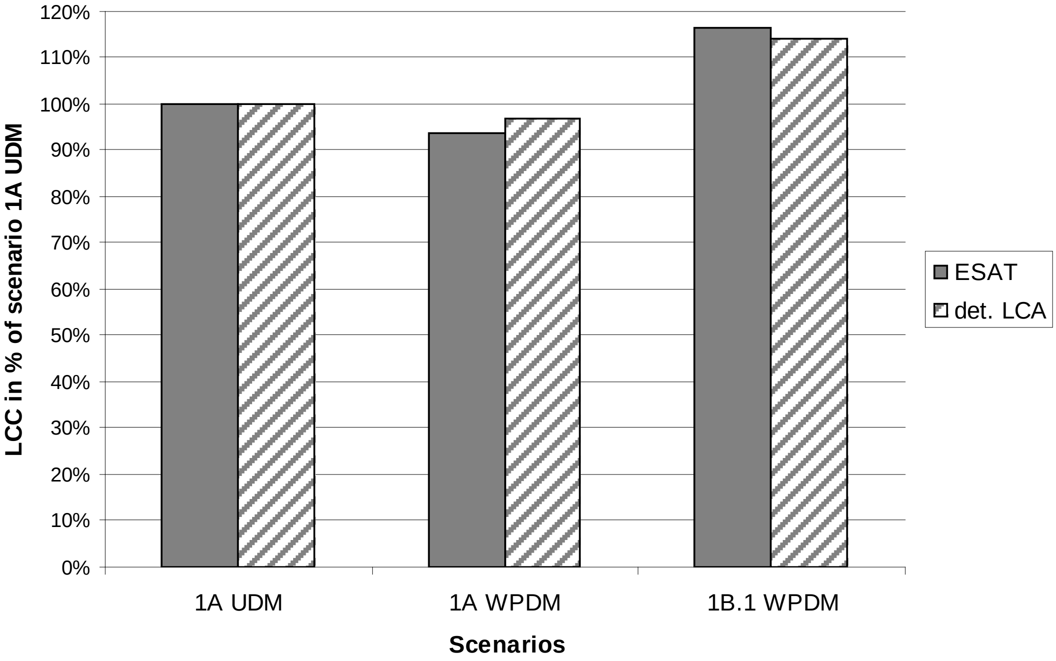
**Fig. 3.** Eutrophication potential as a percentage of scenario 1A UDM calculated by ESAT versus data of the detailed LCA report (Grant and Opray 2005, Sharma A et al. 2005) for the three proposed Kalkallo development water servicing scenarios.



With regard to the outcomes of the comparative economic assessment, ESAT was shown to calculate slightly lower absolute LCCs for scenarios 1A UDM and 1A WPDM and a slightly higher LCC for scenario 1B.1 WPDM; although the relative magnitude difference between ESAT and the detailed LCC study’s outputs were less than 5% across all scenarios.

Reasons for these discrepancies were thought to have related to a combination of: the relatively simple total pipe construction cost calculation in ESAT; having made different data assumptions for annual maintenance costs of water servicing options; and the different data sources used for the capital expenditure component of the water supply and treatment infrastructure.

**Fig. 4.** Life cycle costs as a percentage of scenario 1A UDM calculated by ESAT versus data of the detailed LCA report (Grant and Opray 2005, Sharma A et al. 2005) for the three proposed Kalkallo development water servicing scenarios.

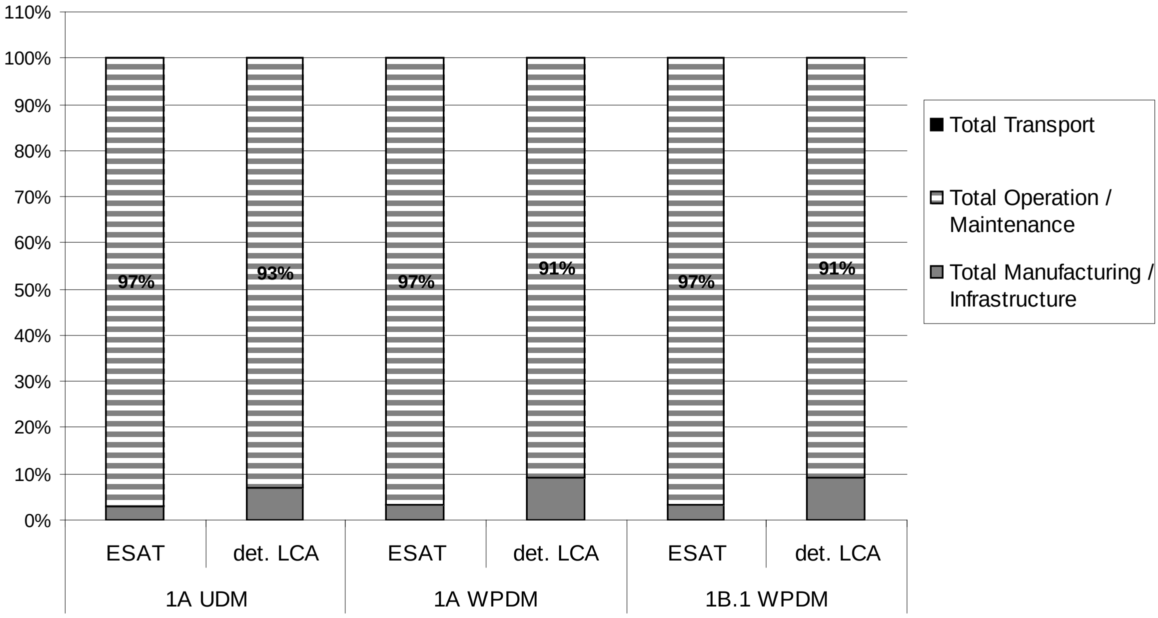


Whereas the capital expenditure associated with reticulation infrastructure dominates the LCC for each of the chosen water servicing scenarios for the Kalkallo development, the vast majority of the environmental burdens come from the operation and maintenance phase. For example, ESAT results for scenario 1A UDM show that this phase accounts for 97.4% of the total environmental burden in GHG emissions, and 96.8% and 96.7% in scenarios 1A WPDM and 1B.1 WPDM respectively. Within the operation and maintenance phase itself, the GHG emissions relating to electricity production and consumption (e.g., from pumping and/or treating water) account for 92% of the total emissions in the scenarios without water recycling and 93% in scenario 1B.1 WPDM. This shows the overbearing dominance of pumping and treatment energy requirements in terms of the environmental impact of urban water service provision and this observation reflects the findings of prior research (e.g., Lundie et al. 2005).

Calculated GHG emissions relating to the production of water servicing infrastructure were slightly higher (≈4–6%) in the results of the detailed LCA compared with those obtained using ESAT. The reason for this small difference in results between the two approaches were thought to have related to: the crude pipe materials estimation process; the way in which large treatment plant infrastructure is accounted for; and/or the omission of other minor infrastructure works in the ESAT model. Without having access to the raw LCI data of the detailed study, however, no further insights as to the sources of this variation can be provided. ESAT also provides the user with an analysis of the GHG emissions resulting from transport activities; however, the contribution of transport to all three investigated scenarios was negligible (<0.2%). Equally, the GHG credits that can be realised from avoided fertiliser use due to biosolids application are minor at around 0.2% of the total figure. This information is shown in Fig. 5 in terms of the contribution of each of the different life cycle phases to the total GHG emissions.

It should be noted that due to the main goal of this paper, which was to compare the accuracy of results obtained through ESAT with the results from detailed LCA/LCC studies, no sensitivity analysis was performed. If the main goal had been to compare the environmental and economic impacts of different water servicing scenarios for the Kalkallo development by using ESAT, obviously a sensitivity analysis testing different assumptions around infrastructure items, their operation or climatic conditions would have been an essential element. In comparison to detailed LCA/LCC investigations, we believe that ESAT would offer enhanced opportunities for scenario testing since alternative scenarios including their respective LCI data are readily at hand.

**Fig. 5.** Relative contributions to total greenhouse gas emissions calculated by ESAT versus data of the detailed LCA report (Grant and Opray 2005, Sharma A et al. 2005) for the three proposed Kalkallo development water servicing scenarios.



## CONCLUSION

In this paper we have outline the key adjustable input parameters and indicator results we believe to be necessary in a simplified sustainability assessment tool for the urban water industry. With regards to the scenarios assessed in the case study, recycling cost more than demand management but had similar greenhouse emissions and better performance against other indicators. Furthermore, it has been demonstrated that analyses performed using a streamlined sustainability tool such as ESAT can produce results consistent with those from more detailed LCA and LCC studies. Relative differences between the results of ESAT and the full LCA/LCC study were considered small enough that they would be unlikely to change the outcomes of a robust MCA, such that both approaches would ultimately be expected to yield a similar decision outcome. Considering the significant time and resource investments necessary to undertake detailed LCA and LCC studies, ESAT can effectively serve as a rapid and easy to use alternative for informing sustainable decision-making processes. Admittedly, only three scenarios served as the test case for comparing ESAT against more detailed LCA/LCC studies; however, due to the similarity of results shown in the present example across all three scenarios, it can be expected that ESAT would also deliver a robust basis for decision-making in other similar case studies.

Testing ESAT using data from a real-life urban development has revealed possible areas for future improvement of simplified tools. For example, it may be beneficial to further disaggregate the results from the impact indicators such that GHG emissions from different kinds of electricity use could be presented separately to allow for more specific life cycle impact interpretation. Equally, the LCC component could be split to show NPV from capital expenditure versus operational expenditure relating to bulk energy use or energy use from maintenance work. The discrepancy in the results of the eutrophication potential indicator between the two LCA approaches also suggests that further data entry requirements, in this case for specific water treatment performance values, could improve the tool.

In spite of these suggested improvements, one of the specific goals during the development of ESAT was to strike a balance between specificity and generality and also between complexity and simplicity. Modifications such as additional data input requirements and extra analytical capacity, whilst they would enhance the accuracy of ESAT, could also compromise the user friendliness and ease by which results can be obtained and interpreted by decision-makers. Applying ESAT to a real-life scenario here has also shown that creative ways of using ESAT can be applied by the user in order to best represent specific scenarios. For example, two separate scenarios in ESAT were used to model scenario 1B.1 WPDM. Since ESAT was primarily designed for residential developments only, the reuse options for recycled water are limited when it comes to commercial or industrial recycled water reuse. In order to account for the proposed recycled water demand, first the residential reuse for toilet flushing was modelled in one scenario, and then the remaining recycled water demand for outdoor use and toilet use in the other three sectors was accounted for in a separate scenario. In the end, the results from both scenarios were added, but this capacity for a tiered modelling approach may be considered advantageous in certain situations.

Although ESAT's scope is currently limited to the Greater Melbourne area, the tool could easily be expanded to consider other geographical regions in Australia or other regions in the world. The two main adaptations necessary to achieve this would involve obtaining and importing the respective local rainfall records and re-modelling the stormwater treatment scenarios based on the new rainfall data. The updating of transport distances and cost data (if appropriate) would be expected to require only minor additional effort. Also, the default option of using one of the two major Melbourne STPs could easily be expanded to consider other locations and treatment plants. Furthermore, the market for decentralised water and wastewater treatment systems is developing rapidly which may lead to the requirement of updating LCI data for this part of ESAT also. However, the fact that ESAT is developed in the commonly available MS Excel® software should make these updates comparatively straight forward.

Simplified sustainability assessment tools like ESAT will be most useful in early phases of infrastructure planning when detailed information is not yet available and rough guidance about the environmental and economic consequences of certain water servicing options is required. This initial screening assessment can probably be achieved by a tool such as ESAT for an order of magnitude or lower cost relative to that of a full LCA and LCC. In addition to the likely cost benefits, there is also the added benefit of avoiding the potentially lengthy time delays in acquiring detailed results from specialist LCA/LCC analysts. Future development and enhancement of ESAT could involve adding additional climate data to allow for application of the tool to other Australian cities and towns. Additionally, and as a detailed process modelling tool, it may be worthwhile combining ESAT with one of the input–output based modelling tools to populate the lower production orders and generate hybrid process/input–output LCA results for a more thorough environmental assessment.

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