Importance of lifespan of sewer systems when estimating environmental impacts using a life cycle

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Summary of key findings

The objective of this paper is to provide a comprehensive inventory for the construction of sewer systems (SS) that includes renovation processes, which are dependent on the lifespan of the SS infrastructure. That inventory is encapsulated in a user-friendly tool (in Excel®), which allows for the systematic incorporation of SS construction in LCA studies. A part from estimating the contribution of renovation of SS on the environmental impacts, this paper also illustrates through a case-study the usefulness of the Excel-based tool to analyze the factors influencing the most the construction and renovation of SS. The results show that renovation of sewer systems should not be neglected in LCA studies. The type of tube material and road construction are the factors influencing the most the construction and renovation processes.

Background and relevance

Improved design or optimal operation can increase environmental sustainability of urban wastewater systems (UWSs) and Life Cycle Assessment (LCA) has been a widespread tool for that purpose (Corominas et al., 2013). However, many LCA studies applied to UWS include only the operation phase but neglect (or understudy) the environmental load of the construction and demolition phases. The review of Loubet et al. (2014) on UWSs indicates that only 13 studies (out of 18) included in the inventory the material used for the construction of sewer systems. However, none of the studies included in the inventory the resources consumed or impacts generated from civil works. That was further addressed in the paper from Risch et al. (2015). What has not been deeply addressed yet is the importance of lifespan of SS infrastructure, which is dependent on the type of material and on the environmental conditions in the sewer pipes and might lead to renovation of the infrastructure. This renovation has not been properly taken into account in previous LCA studies.

We believe that construction and renovation (especially for SS) are not systematically included in the LCA studies due to the limited availability of comprehensive Life Cycle Inventories (LCI). Hence, the objective of this paper is to provide a comprehensive inventory for the construction of SS that includes renovation processes and to illustrate the usefulness of such inventory by applying to a case-study.

Results

Sewer pipes construction and renovation processes

The process to construct a pipeline can be divided into 6 different steps: 1st) the working area is cleaned; 2nd) the trench is excavated; 3rd) the tube is placed at the bottom of the trench above a layer of draining material; 4th) the trench is refilled with granite sand, and normal sand which is taken from the same workplace or sand taken from elsewhere; 5th) if there is traffic on top of the trench, a layer of asphalt is included, and 6th) the excavated soil not used is distributed around the working area or transported and deposited in a landfill. Six different steps are also considered for the renovation: 1st) breaking the asphalt layer and deposition of the material; 2nd) excavation of the trench; 3rd) extraction of the old tube; 4th) substitution with the new one; 5th) refilling the trench and 6th) including a layer of asphalt when is necessary.

System boundaries

The system boundaries considered in this study (Fig. 1) include processes for pipeline construction, renovation and end-of-life.

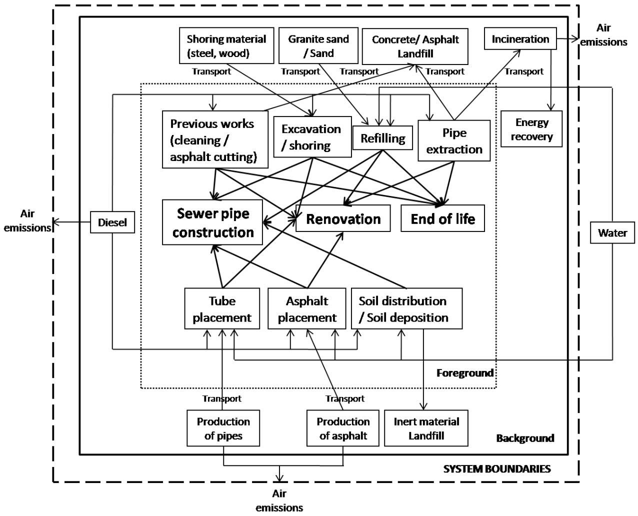

Fig. 1. System boundaries of sewer systems including renovation

Inventory tool for sewer systems

To facilitate the creation of material and energy inventories and the assessment of LCA impacts for the construction and renovation of pipelines, a semi-automatic tool was created in Excel. This tool automates the key steps to obtain the inventory data. Data were obtained from BEDEC database (www.ITEC.cat) and Ecoinvent databases.

Environmental impact profile of renovation vs construction of pipelines

Reference case (the importance of renovation). To proof the usefulness of the proposed comprehensive inventory we evaluated the environmental impact of construction and renovation processes of a pipeline of 1 km of length, with a PVC tube of 40 cm of diameter. The pipeline is located in a non-urban area, without traffic in the upper part of the trench, installed in a compact soil, in a rectangular trench with no-shoring. The distances of 50 and 25 km were selected between the granite sand distributor and tube distributor to the workplace. A lifetime of 70 years of operation was considered, it means that considering a median lifetime of 25 years for PVC tubes, the construction and 2 renovations were considered.

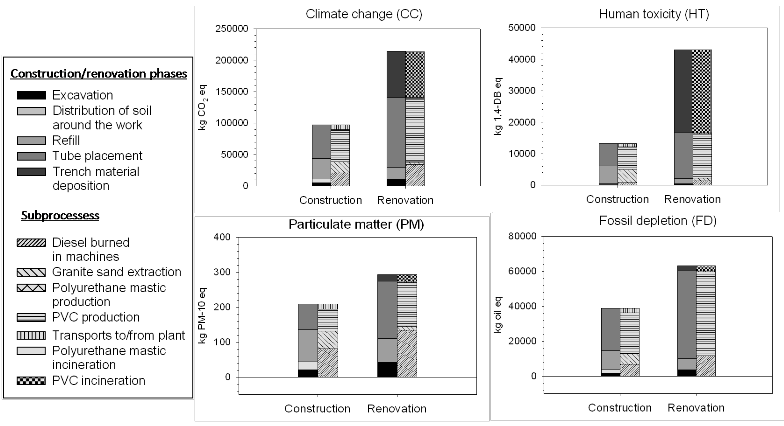

Fig. 2. LCIA results for the case study. For each impact category we show the construction and renovation phases contribution. Also, for each of them we show the contribution of the construction/renovation phases and of the subprocesses. Calculations were made using SimaPro 8.0.3 and ReCiPe 1.09 method.

Figure 2 shows the impact assessment for the 1 km pipeline evaluated. For all impact categories, the renovation process has always larger impacts compared to the construction. With regards to the construction phase, refilling and tube placement are the phases with largest contribution to the impact. Tube placement has more importance for climate change (CC) and fossil depletion (FD) impact categories because this phase includes also the contribution of the PVC tube production, and the tube has a large contribution to these impacts. The refilling phase has an important contribution on the particulate matter (PM) impact category due to the combination of the granite sand production and diesel used for the machines. For human toxicity (HT), both subprocesses have similar contribution to the overall impact. Looking at the renovation, besides tube placement, deposition of trench material is significantly contributing to the impacts (especially for CC and HT). In fact, that deposition involves incineration of the PVC tube, a process which has a significant environmental impact due to direct emission of carbon dioxide and other toxic substances during the incineration of the own tube to the air, as well as, the contribution of other chemicals used during the incineration process. When analyzing the contribution of subprocesses, the production of PVC (both for construction and renovation) is the main source of impact for CC, FD and HT. Trench material deposition impacts are mainly driven by PVC incineration. Diesel burned in machines is having a significant contribution on the PM impact category (39% contribution on the construction and 46% on the renovation).

Sensitivity analysis. With regards to site-specific conditions, road construction is one of the most important factors to consider in the inventory (this is clearly observed in the CC and FD impact categories) (Table 1), mainly because of the usage of bitumen, which has a large environmental impact. The second factor with largest importance is the presence of rocky soil, which significantly increases the usage of machinery. With regards to tube material, reinforced concrete is the one with the largest impact in most impact categories (e.g. CC, HT and PM). When using plastic, HDPE would be recommended against PVC, given the assumptions taken in this paper regarding lifespan of the materials (20 to 30 years for PVC, 30 to 50 for HDPE and 50 to 90 for tubes with concrete).

Table 1. Environmental impacts of different types of sewer system trenches. Percentages refer to the lifespan of the tube material (20 to 30 years for PVC, 30 to 50 for HDPE and 50 to 90 for concrete).

	Climate change (kg CO_{2eq}*$year^{-1}$)		Human toxicity (kg 1,4-DB_{eq}*$year^{-1}$)		Particulate matter (kg PM-10*$year^{-1}$)		Fossil depletion (kg oil_{eq}*$year^{-1}$)	
	Mean	Life span	Mean	Life span	Mean	Life span	Mean	Life span
Reference	$4.44\cdot10^3$	+34.5%	$8.03\cdot10^2$	+38.4%	$7.18\cdot10^1$	+29.1%	$1.46\cdot10^3$	+30.9%
Soft soil	$4.43\cdot10^3$	+34.5%	$8.04\cdot10^2$	+38.3%	$7.13\cdot10^1$	+30.0%	$1.45\cdot10^3$	+31.1%
Rocky soil	$5.19\cdot10^3$	+28.9%	$8.76\cdot10^2$	+34.9%	$9.59\cdot10^1$	+20.6%	$1.75\cdot10^3$	+25.2%
Road construction	$5.38\cdot10^3$	+34.8%	$9.53\cdot10^2$	+38.0%	$9.57\cdot10^1$	+20.4%	$2.25\cdot10^3$	+32.3
Urban setting	$4.53\cdot10^3$	+33.8%	$8.19\cdot10^2$	+37.5%	$7.31\cdot10^1$	+28.6%	$1.52\cdot10^3$	+29.6%
Concrete	$2.78\cdot10^3$	-46.0%	$4.14\cdot10^2$	-42.5%	$7.25\cdot10^1$	-47.0%	$7.61\cdot10^2$	-45.7%
Reinforced concrete	$4.04\cdot10^3$	-47.5%	$1.04\cdot10^3$	-47.3%	$1.19\cdot10^2$	-49.3%	$1.05\cdot10^3$	-47.0%
HDPE	$3.04\cdot10^3$	+54.6%	$2.66\cdot10^2$	+47.0%	$5.60\cdot10^1$	+34.3%	$1.24\cdot10^3$	+43.1%

Discussion

Renovation of pipelines has to be included in life cycle assessments that include sewer systems. Otherwise, the environmental impacts are underestimated.

Besides the tube material, civil works have to be considered. Site-specific conditions play an important role in the overall impacts. Specially, the presence of rocky soil or the use of bitumen when a road on top of the trench has to be constructed.

All calculations shown in this paper were obtained thanks to the automatic tool, which was developed to facilitate the development of material, and energy inventories for the construction and renovation of pipelines, and the calculation of environmental impacts and costs. This tool can easily be expanded and adapted to include other processes, which might be relevant in other countries.

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