Environmental and economic assessment of a pilot stormwater infiltration system for flood prevention in Brazil

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Abstract:

Green and grey stormwater management infrastructures, such as the filter, swale and infiltration trench (FST), can be used to prevent flooding events. The aim of this paper was to determine the environmental and economic impacts of a pilot FST that was built in São Carlos (Brazil) using Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). As a result, the components with the greatest contributions to the total impacts of the FST were the infiltration trench and the grass cover. The system has a carbon footprint of 0.13 kg CO_2eq./m^3 of infiltrated stormwater and an eco-efficiency ratio of 0.35 kg CO_2eq./USD. Moreover, the FST prevented up to 95% of the runoff in the area. Compared to a grey infrastructure, this system is a good solution with respect to PVC stormwater pipes, which require a long pipe length (1070 m) and have a shorter lifespan. In contrast, concrete pipes are a better solution, and their impacts are similar to those of the FST. Finally, a sensitivity analysis was conducted to assess the changes in the impacts with the varying lifespan of the system components. Thus, the proper management of the FST can reduce the economic and environmental impacts of the system by increasing its durability.

Keywords: Life Cycle Assessment, Life Cycle Costing, Best Management Practices, climate change adaptation, urban flood, filter, swale and infiltration trench

1. Introduction

1.1 Floods and stormwater Best Management Practices (BMP)

Flooding events are commonplace in many cities of the world. The agents that lead to this phenomenon include the precipitation intensity, stormwater volume, time span of the precipitation event and degree of urbanisation, among many others (Kundzewicz et al., 2007). With more than 50% of the world's population living in urban areas (UN, 2012), changes in land use become apparent, and the degree of soil imperviousness increases, especially in developing countries. As a result, there is an increase in the stormwater runoff and a subsequent reduction in the infiltration rate. Hence, urbanisation affects the occurrence of floods when the lack of permeability is combined with sudden and intense precipitation (Butler and Davies, 2000). In addition to being a source of water pollution and natural damage, these events also result in relevant economic and social costs because of building and personal property damage (Ntelekos et al., 2010).

Therefore, stormwater runoff must be properly managed to prevent floods and to protect water resources and public health (US EPA, 2013). The so-called stormwater "Best Management Practices" (BMPs) are of paramount importance in terms of flood risk reduction and can be applied in urban areas under several configurations. These strategies are commonly classified into grey and green infrastructures (**Figure 1**). The former consist of traditional practices in the field of urban drainage, such as sewers or detention tanks, and normally have a single function, e.g., to store and transport water. In contrast, the latter are multifunctional integrated systems that are designed to deliver ecosystem services in urban and rural areas (European Commission, 2013). This is the case of infiltration trenches, green roofs or permeable pavements. In this study, most attention is paid to filter, swale and infiltration trenches (FST), which are complex, decentralised systems.

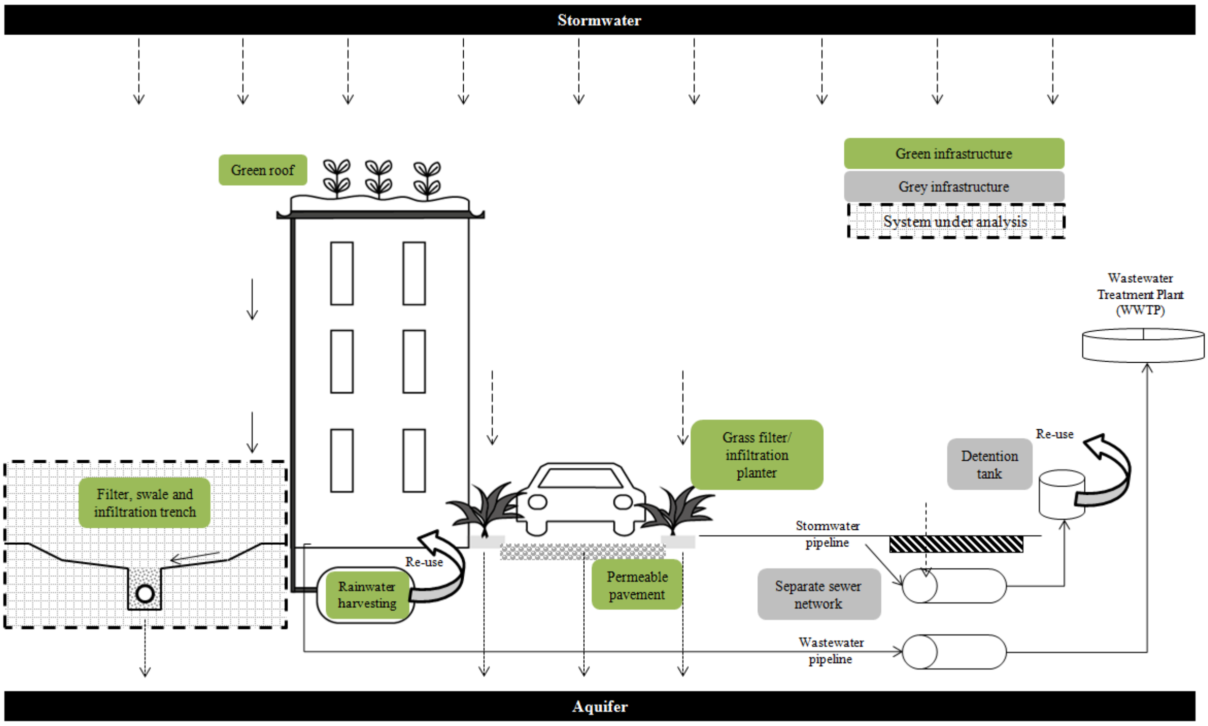

Figure 1 Strategies of different types of stormwater BMP in urban areas and the system under analysis

In general, all of the options reduce the quantity of stormwater runoff that needs to be transported through conventional sewers by disconnecting storm- and wastewater pipelines (Semadeni-Davies et al., 2008) or by implementing other alternative systems (Butler and Davies, 2000). In the case of green roofs, for instance, Lee et al. (2013) reported that the stormwater retention capacity is high when the rainfall intensity is lower than 20 mm/h. Therefore, the efficiency of green roofs varies depending on the climate, among other aspects. In this respect, the installation of green roofs in 10% of the buildings in Brussels (Belgium) would result in a 54% runoff reduction (Mentens et al., 2006). In Michigan (USA), a 63-94% reduction could be achieved in extensive green roofs during heavy and light rainfall events, respectively (Getter et al., 2007).

Moreover, techniques involving a layer of vegetation can also improve the stormwater quality and quantity, given that plants are natural filters (**Table 1**). In this sense, grass filters and swales can reduce pollutant loads by 46-86% (Deletic and Fletcher, 2006). In addition, vegetated systems induce the natural infiltration of stormwater to aquifers when in contact with the soil. In the case of grey infrastructure, stormwater can be re-used for non-potable purposes, such as watering, when it is collected by means of storage tanks. In this way, stormwater can be envisioned as a resource. However, separate sewers have only been adopted in some regions because of the economic costs their construction entails. Alternatively, detention tanks are also beneficial, as they can induce a 45% reduction in the discharge impacts of combined sewers in a Mediterranean basin (Llopart-Mascaró et al., 2014).

Table 1 General features of different stormwater BMPs. Adapted from the SMRC (2014) and San Francisco Stormwater Design Guidelines (2010)

	BMP	**Management**		**Water treatment capacity**		**Applicability in high density areas**	**Climatic limitations**[2]	**Economic aspects**[3]
		Centralised	**Decentralised**[1]	**Natural**	**Inexistent**			
Green	Infiltration basin		▨	▨			MR	CE
	Green roofs		▨	▨		▨	EC	HC
	Bio-retention tanks/basins/rain gardens		▨	▨		▨	MR	LC
	Permeable pavements		▨		▨	▨	NC	LC
	Grassed filter strips/swales/infiltration planter		▨	▨			NA	LC
	Infiltration trench		▨	▨			MR	HC
	Constructed wetlands		▨	▨			NA	HC
	Rainwater harvesting		▨	▨	▨	▨	-	LC
Grey	Separate sewer networks	▨			▨	▨	-	HC
	Detention tanks	▨			▨	▨	-	HC

[1] Disconnected from the general network directing water to the Wastewater Treatment Plant (WWTP)

[2] MR: Modifications required in cold and arid regions; NA: Not applicable in arid regions; NC: Not applicable in cold regions; EC: Must tolerate extreme conditions

[3] CE: Cost-effective; LC: Low economic cost; HC: High economic cost

Generally, BMPs can be implemented in most areas, but they are especially relevant in wet regions or areas with intense rainfall events. In the long term, local and national administrations must keep this issue in mind, given that the current situation of climate change might lead to an increase in the rainfall intensity and peaks worldwide. This phenomenon might be particularly notable at mid and high latitudes (Meehl et al., 2007), and current management systems might become insufficient for addressing stormwater. Therefore, these regions should be thoroughly studied considering both urbanised areas and future building projects.

1.2 Environmental and economic assessment of stormwater BMPs

Different studies have analysed the environmental effects of various BMPs. To do so, Life Cycle Assessment (LCA) (ISO, 2006) is a suitable tool that helps to calculate and discuss the environmental burdens of the life cycle stages of a system, i.e., from raw material extraction to end of life. From this perspective, it was determined that green roof surfaces have lower environmental impacts than conventional rooftops. The former reduce the heating and cooling requirements of a building and extend the lifespan of the roof by protecting the roof membrane (Kosareo and Ries, 2007; Saiz et al., 2006).

In the case of bio-infiltration rain gardens, the construction stage accounts for the major environmental and economic costs because of the contributions of silica sand and bark mulch (Flynn and Traver, 2013). In contrast, the operation stage entails a series of avoided burdens, such as carbon sequestration (40 kg C/year), and the relative impacts are thus lower. Carbon sequestration is common in vegetated layers; as a result, green roofs can also sequester up to 375 g C/m^2 per year according to some estimates (Getter et al., 2009). Similarly, grass filters and swales remove up to 5 kg C/m^2 per year when located next to roadways in the USA (Bouchard et al., 2013).

Furthermore, BMPs can perform additional functions apart from stormwater management. Wastewater treatment is a key function of constructed wetlands and, in this case, the construction phase also plays an important role (Risch et al., 2011). Still, those treatments consisting of vertical flow reed bed filters have up to 3 times less impact than do conventional activated sludge technologies (Risch et al., 2014). Similarly, rainwater harvesting systems can be used in dry areas to take advantage of a scarce resource. In addition to re-using rainwater for non-potable purposes, installing domestic storage tanks is feasible in drier regions, such as the Mediterranean (Farreny et al., 2011). Given that tanks can be smaller than in regions where more rainwater can be collected, their carbon footprint is also smaller (EA, 2010). Construction materials might account for up to 95% of the environmental impacts when the tank is placed on the roof (Angrill et al., 2012). In addition, the location of the tank plays an important role, and an exergy or useful-energy analysis determined that placing the tank on the roof of buildings with a relatively high density is the most efficient option (Vargas-Parra et al., 2013).

Additionally, green and grey infrastructures can be compared considering an equivalent reduction of stormwater runoff. For instance, de Sousa et al. (2012) achieved a 77-95% impact reduction when a combination of green infrastructures (e.g., permeable pavements, bio-retention tanks and infiltration planters) was implemented instead of end-of-pipe detention tanks with or without treatment. The former scored better because of their potential to sequester carbon and reduce the treatment requirements.

In terms of cost-efficiency and economic assessments, some literature already exists. Bio-retention basins are the most suitable option for reducing pollutant loads from a cost-efficiency point of view compared to other BMPs and grey infrastructures (Wang et al., 2013). Considering extensive green roofs, Life Cycle Costing (LCC) reported that the costs of this system are lower than those of conventional roofs (Wong et al., 2003) and that the investment can be recovered in 10 years (Chan and Chow, 2013). With respect to rainwater harvesting systems, Vargas-Parra et al. (2014) determined that, in the city of

Barcelona, tanks that are installed in clusters of buildings have 30% better financial outcomes than do those that are installed in single buildings.

Therefore, as much as cities can benefit from preventive infrastructures, their implementation also entails a series of environmental and economic impacts because of the materials and energy that are required for their construction and use. For this reason, a net balance between the benefits and costs of integrating a certain type of BMP in an urban area should be estimated. By so doing, the environmental and economic feasibility of the system could be determined. In this sense, this paper aims to calculate the environmental and economic impacts of a specific type of BMP as a first step towards the estimation of a net balance.

So far, several analyses have been conducted in the field of BMPs. However, little data exist on the environmental and economic impacts of filter, swale and infiltration trenches (FST). This is a complex, decentralised source-control system combining 3 interconnected types of BMP (i.e., grass filter, infiltration swale and infiltration trench). This system requires rather expanse areas and can also be implemented as a flood mitigation technique, especially in wet regions. Therefore, conducting an LCA and LCC of this system is of interest to help reduce the negative effects deriving from its life cycle. Additionally, a comparison with another type of BMP can be useful in determining the actual feasibility of implementing a source-control device with respect to other alternatives.

2. Goal

This study has 2 main objectives: to calculate and discuss the environmental and economic impacts of building a pilot FST and to compare the impacts of the FST with those of a centralised stormwater BMP, such as a stormwater separate network. To do so, the specific goals of this analysis were to compose an inventory of the quantity and costs of the material and energy inputs in the life cycle of an FST located in an area with high rainfall intensity; to identify the environmental impacts of an FST using LCA and the main elements affecting these results; to identify the major contributors to the economic costs of an FST using LCC; and to assess the effect of the lifespan of the system components on the final results.

3. Materials and Methods

3.1 Functional Unit

The functional unit (FU) that was considered in this analysis was 1 m^3 of stormwater that was infiltrated by an FST. The system has an average lifespan of 10 years (USDT, 2014) and was built in a region with an average annual rainfall of 1500 mm.

3.2 Description of the FST

The FST under analysis is a real-scale system that was built in 2009 on the campus of the Federal University of São Carlos (UFSCar) (São Paulo, Brazil). This system is intended for the quantity control and quality improvement of the stormwater runoff. This BMP prevents flooding events by collecting stormwater coming from the roof of the Department of Medicine, which has an area of 1701 m^2. This water is then transported by the different parts of the system with the aim of directing it to the aquifer. The runoff follows a series of steps before reaching the target (**Supplementary Material 1**). First, rainwater collected at the roof is conducted through a (1) pipe network and (2) a subsequent channel (0.60×7 m) to a triangular weir, where the water flow can be measured and controlled. Then, this water flow is distributed via (3) a manifold with a perforated pipe and (4) a 4-metre-wide grass filter with a 2% slope. Finally, the water reaches (5) the swale and (6) the infiltration trench, where the stormwater flows into the soil (and later to the aquifer or returns to the atmosphere) and/or (7) to an overflow weir when the FST is full.

On average, the FST receives 5,930 m^3 of stormwater per year, considering a catchment surface of 3901.3 m^2 and an average rainfall of 1520 mm between 1961 and 2013 (INMET, 2014). However, this system has a maximum storage capacity of 110 m^3, according to the design and hydro-geological parameters that were defined by Lucas et al. (2013). The area requirements of the entire system are approximately 600 m^2.

3.3 System boundaries and inventory data

The life cycle stages that were included in the environmental and economic analysis were raw material extraction, production of manufactured goods, transport to the construction site and construction of the channel, manifold, infiltration trench and grass cover (**Figure 2**). The grass cover consists of the grass filter and infiltration swale. Other elements, such as the pipe and gutters that are required to collect the runoff, were not considered, as they are related to the structure of the Medicine building and are also required for other types of infrastructures (i.e., grey and green). In addition, these elements were constructed before the FST existed; therefore, they were excluded from the analysis. Regarding the other life cycle stages, demolition accounted for the energy that was required to deconstruct the infrastructure, and it was assumed that all of the materials were disposed of in an inert material landfill at the end of their service life. The grass cover was left aside as it degrades on-site and is bound to disappear due to erosion. The operation accounted for the carbon sequestration potential of the system, but the maintenance was excluded from the analysis given that it was considered negligible and linked to the end of the service life of the system.

In general, an FST has an estimated lifespan of 10 years; however, depending on the rainfall intensity, the quality of the stormwater runoff and the management of the system, the FST can last more or less time. Therefore, a sensitivity analysis was conducted to assess the influence of the lifespan of the different components of the FST on the total impacts of the infrastructure.

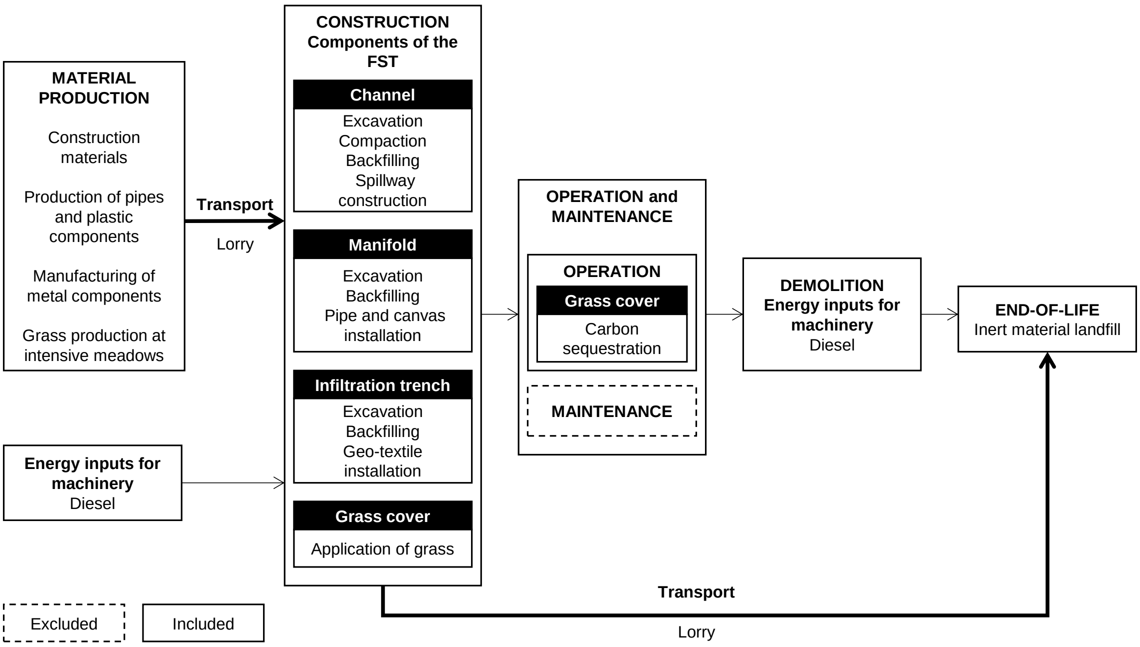

Figure 2 System boundaries of the FST

Regarding the inventory data (**Table 1**), the dimensions of the infrastructure were obtained from the original construction plans, which provided high-quality data that were used to estimate the material and energy flows that were required to build the FST. The standard diesel requirements of the machinery that were used to compact and backfill were retrieved from the MetaBase ITeC (2010). Of all of the subsystems, soil compaction only occurs in the channel, given that the soil in the other parts of the FST must remain porous to enable infiltration and that no machinery is used. In the case of transport, an average distance of 30 km was assumed for the transport of locally sourced materials to the construction site (e.g., concrete, plaster, gravel or sand). In addition, 100 km were considered as the average distance covered to transport plastics and metals, and 10 km was the distance to the landfill (Doka, 2003).

To estimate the carbon sequestration of the grass cover, the annual rate that was reported by Bouchard et al. (2013) for grass covers that are younger than 21.5 years (0.099 kg C/m^2/year) was applied. The annual carbon sequestration was converted to kg CO_2eq. using the US EPA's Greenhouse Gas Equivalencies Calculator (US EPA, 2014).

Table 1 Inventory data for an FST with a maximum storage capacity of 110 m^3 of stormwater and a lifespan of 10 years

Materials and processes	Channel	Manifold	Infiltration trench	Grass cover
Construction				
Concrete (m^3)	7.5E-01			
Concrete block (kg)	1.6E+03			
Brick (kg)	1.1E+03			
Roughcast plaster (kg)	3.4E+02			
Cast iron (kg)	5.2E+01			
Steel (kg)	8.3E+01			
Gravel (kg)		1.1E+04	7.0E+04	
Sand (kg)			7.7E+03	
Perforated polyvinylchloride (PVC) pipe (kg)		8.5E+01	5.8E+00	
Polyethylene-made (HDPE) plastic canvas (kg)		6.1E+00		
Polyester (geo-textile) (kg)			5.2E+01	
Grass (kg)				1.1E+04
Metal product manufacturing (kg)	1.4E+02			
Extrusion process (plastic pipes) (kg)		8.5E+01	5.8E+00	
Extrusion process (plastic films) (kg)		6.1E+00		
Diesel (MJ)	1.1E+03	2.7E+03	1.4E+04	
Transport				
To construction site (tkm)	3.2E+02	6.7E+02	4.7E+03	6.7E+02
To landfill (tkm)	9.9E+01	2.2E+02	1.5E+03	
Demolition				
Diesel (MJ)	9.1E+02	3.2E+02	2.3E+03	3.5E+02
End-of-life				
Waste to inert landfill (kg)	4.9E+03	1.1E+04	7.7E+04	

3.3.1 Environmental calculation tools

Of all of the stages that were included in the LCA methodology (ISO, 2006), only the classification and characterisation were considered in the impact assessment. The method that was used was the hierarchical approach of ReCiPe 2008 (Goedkoop et al., 2009), and the mid-point indicators that were selected were Climate Change (CC, kg CO_2 eq.), Ozone Depletion Potential (ODP, kg CFC-11 eq.), Human Toxicity Potential (HTP, kg 1,4-DB eq.), Photochemical Oxidant Formation Potential (PCOP, kg NMVOC), Terrestrial Acidification Potential (TAP, kg SO_2 eq.), Freshwater Eutrophication Potential (FEP, kg P eq.), Marine Eutrophication Potential (MEP, kg N eq.), Water Depletion Potential (WDP, m^3), Metal Depletion Potential (MDP, kg Fe eq.) and Fossil Depletion Potential (FDP, kg oil eq.). The Cumulative Energy Demand V1.08 (CED, MJ) was also selected to evaluate the energy issues. The ecoinvent 2.2 (ecoinvent, 2009) database, which is linked to the software SimaPro 7.2.0 (PRé Consultants, 2010), was used to evaluate the emissions that were related to the materials and energy. All of the processes were adapted to the Brazilian electricity mix during the year 2009.

3.3.2 Economic calculation tools

To conduct the economic assessment, ISO 15686-5:2008 was used for guidance (Nederlands Normalisatie-Institut, 2008). Detailed data on the planning, construction and management of the system were also obtained from the original project. The prices that were reported were related to the year 2008, when the FST was designed. To account for the prices in 2009, when the system was actually built, the present value (PV) was calculated. To do so, an inflation rate of 4.31% was considered for Brazil during this period (IMF, 2014). In the LCC, the Total Cost (TC) accounted for the costs that were associated with the processes that are presented in **Table 1**, as well as professional fees (e.g., labour, project design and engineering) and temporary works.

4. Results and discussion

In this section, a comparison of the components of the FST under analysis is presented (**Section 4.1**). In **Section 4.2** the feasibility of the system is analysed compared to the case of a stormwater network performing approximately the same function. Finally, **Section 4.3** addresses a sensitivity analysis of the FST considering different lifespan scenarios of the system components.

4.1 Performance of the FST

After conducting the global environmental and economic assessment, the different components of the FST were compared (**Figure 3**). The infiltration trench presented the greatest contributions in 50% of the impact indicators with up to 78% of the burdens, including the CC and TC. The trench was the component with the biggest dimensions and thus the greatest material and energy requirements (**Table 1**). In general, the diesel that was consumed by the construction machinery was one of the processes that affected the results the most, as it accounted for 20-60% of the impacts (**Supplementary Material 2**). Despite being a vegetated surface, the grass cover also displayed relevant contributions in 4 indicators (40-92%). In this case, the production of grass in intensive meadows resulted in up to 99% of the environmental impacts of this subsystem (**Supplementary Material 2**). In the case of the CC, there were avoided emissions (2,035 kg of CO_2eq. in 10 years) due to carbon sequestration, and the impacts of the grass cover did not surpass 10% of the total CO_2eq. emissions.

In general, the channel and the manifold were the components of the FST with the least impact with a few exceptions. The channel accounted for approximately 60% of the HTP and 80% of the MDP, which results from the manufacturing of the iron cover and the steel-made spillway (**Supplementary Material 2**), given that the metal processing indicates potential damage to human health. In terms of economic costs, there is an element that should not be underestimated. Although the infiltration trench accounted for the greatest costs, the design, planning and other preliminary activities represented 25% of the economic costs of the system.

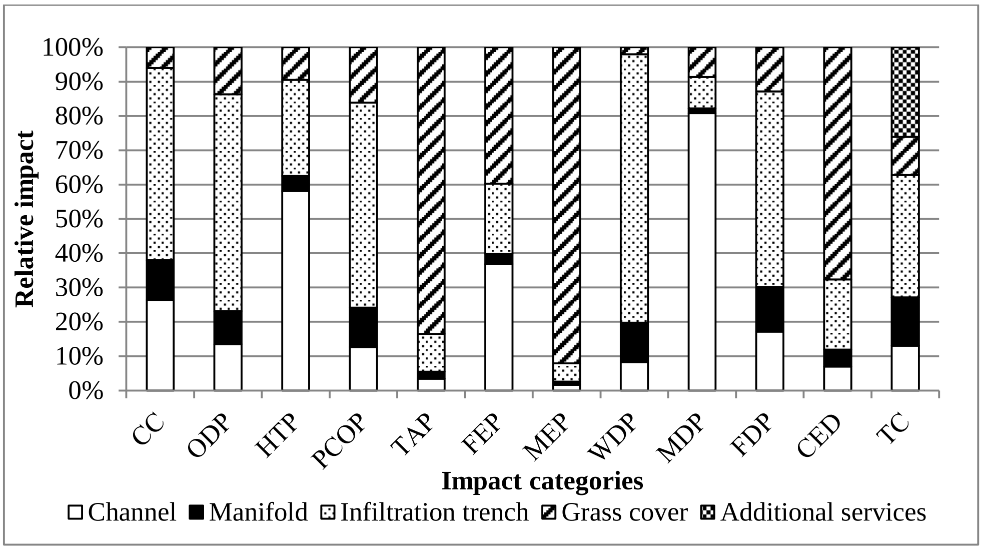

Figure 3 Contribution of the different components of the FST to the environmental and economic costs of the system.

The impacts of the FST as linked to the total stormwater infiltrated in a year were variable because of the annual precipitation patterns. Considering that this system has a lifespan of 10 years, the annual impacts of the FST per m^3 of infiltrated stormwater are shown in **Figure 4** for the period from 2003-2013. As a result, this BMP had an average annual impact of 0.13 kg CO_2 eq./m^3 and 0.37 USD/m^3. Moreover, this infrastructure is efficient in terms of preventing floods. It was assumed that the maximum volume of stormwater that can be stored and infiltrated by the FST cannot surpass 110 m^3 for a precipitation event, according to the estimations made by Lucas (2011). Therefore, the amount of exceeding stormwater that accumulated during a year ranged between 5 and 20% of the total annual stormwater that was received. Consequently, most of the stormwater that was received by the system could be infiltrated, and a significant runoff flow was prevented.

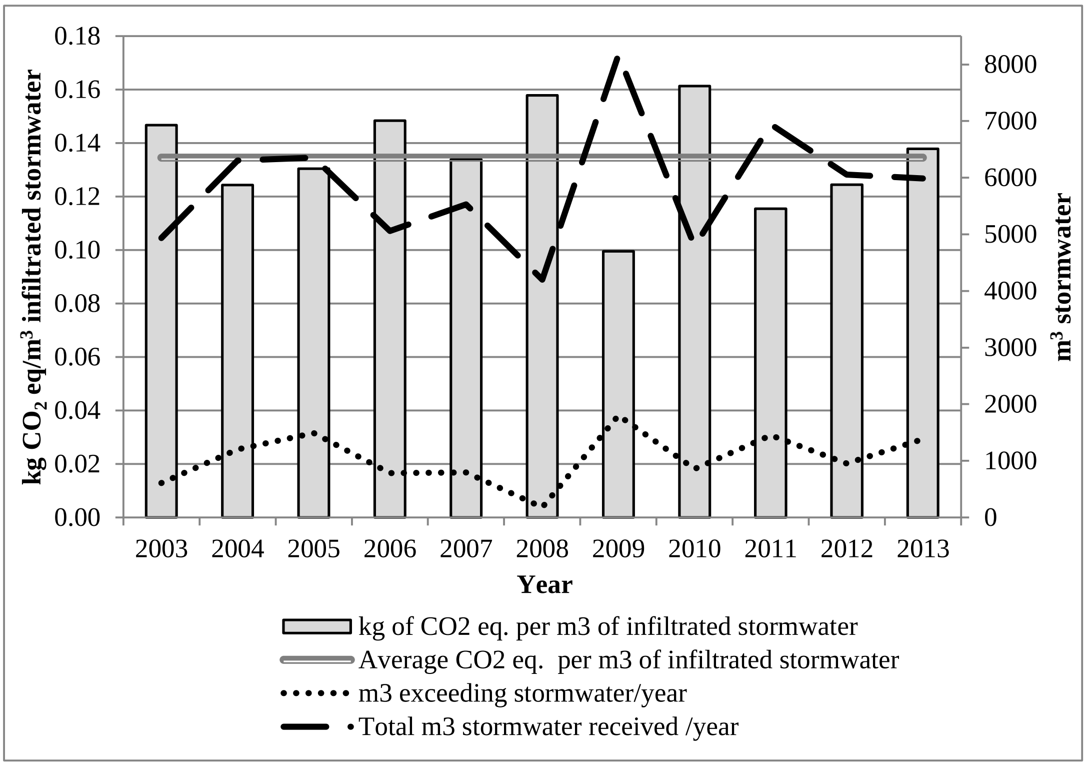

Figure 4 Evolution of the annual CO_2 eq. emissions of the FST per m^3 and the total and exceeding stormwater in the period from 2003-2013.

In addition to these observations, an eco-efficiency ratio could be calculated considering the total environmental impacts and economic costs of the system (**Supplementary Material 3**). For instance, in a time span of 10 years, investing 1 USD to plan and build this FST results in 0.35 kg of CO_2eq. In terms of energy, a ratio of 17.8 MJ/USD was obtained. Considering the results that were reported by Flynn and Traver (2013) for a bio-infiltration rain garden, an eco-efficiency ratio of -0.18 kg CO_2eq./USD can be calculated. In this case, the system presented avoided impacts because the authors accounted for the environmental benefits of the infrastructure (e.g., the reduction of the wastewater treatment requirements and urban forest benefits).

4.2 Comparison of the FST with a grey solution

Alternatively to the FST, stormwater could be managed using other types of infrastructures. Given that the FST belongs to the group of green infrastructures, the FST could be compared with a grey system. In this case, the impact of transporting the annual stormwater that was infiltrated by the FST was assessed considering a certain length of separate stormwater network. To do so, the volume of infiltrated stormwater was calculated for each precipitation event from 2003-2013 with data that were retrieved from INMET (2014). Considering that the daily infiltrated water was transported through a fully charged pipe with a diameter of 300 mm, the average length that is required in an event was calculated. Because different pipe materials can be used in the construction of the networks, the methodology that was presented by Petit-Boix et al. (2014) for the calculation of the impacts of sewer pipes was applied. In this case, sand-bedded polyvinylchloride (PVC) pipes and half-concrete/half-sand-bedded concrete pipes were compared, with a lifespan of 50 and 100 years, respectively. As a result, the average lengths that were required in an event to transport the equivalent volume of stormwater infiltrated by an FST were 600 m for concrete and 1070 m for PVC.

In addition, the system that is environmentally equivalent to an FST could be determined (**Figure 5**). Considering that the FST has an annual carbon footprint of 0.13 kg CO_2eq/m^3, a PVC pipe equalling this impact should be 424 m long, whereas 558 m would be required in the case of concrete. In this sense, concrete pipes are environmentally feasible compared to the FST, given that the length that is needed to infiltrate the same volume of stormwater (600 m) is very similar to the FST-equivalent length (558 m). In contrast, PVC pipes are the least preferable option, given that 1070 m is far above the threshold. Furthermore, the pipe durability also affects the final results, given that concrete pipes last longer (~100 years) than do PVC pipes (~50 years). Consequently, the annual impacts are greater in the case of PVC. On average, the annual impact of transporting stormwater that is infiltrated by the FST is 0.14 and 0.34 kg CO_2eq./m^3 for concrete and PVC pipes, respectively.

Nevertheless, the location of the collection system should also be considered, indicating that a discharge point (e.g., a river, a larger sewer pipe, etc.) can be found at a calculated distance from the collection site. Otherwise, the construction of a separate stormwater network is unfeasible in environmental and constructive terms, and the FST is thus a better source-control solution in this case. In addition, the implementation of the FST could be of interest when a pipeline becomes undersized with an increase in the precipitation regime. This situation could occur because of changes in the precipitation patterns deriving from climate change or an extension of the constructed area. Therefore, the FST could be an adaptation strategy. In this sense, an integrated assessment should also aim at analysing the ecosystem services provided by this system together with LCA in order to offer a multidisciplinary approach and detect further strengths (Lü et al., 2012; Zhang et al., 2010).

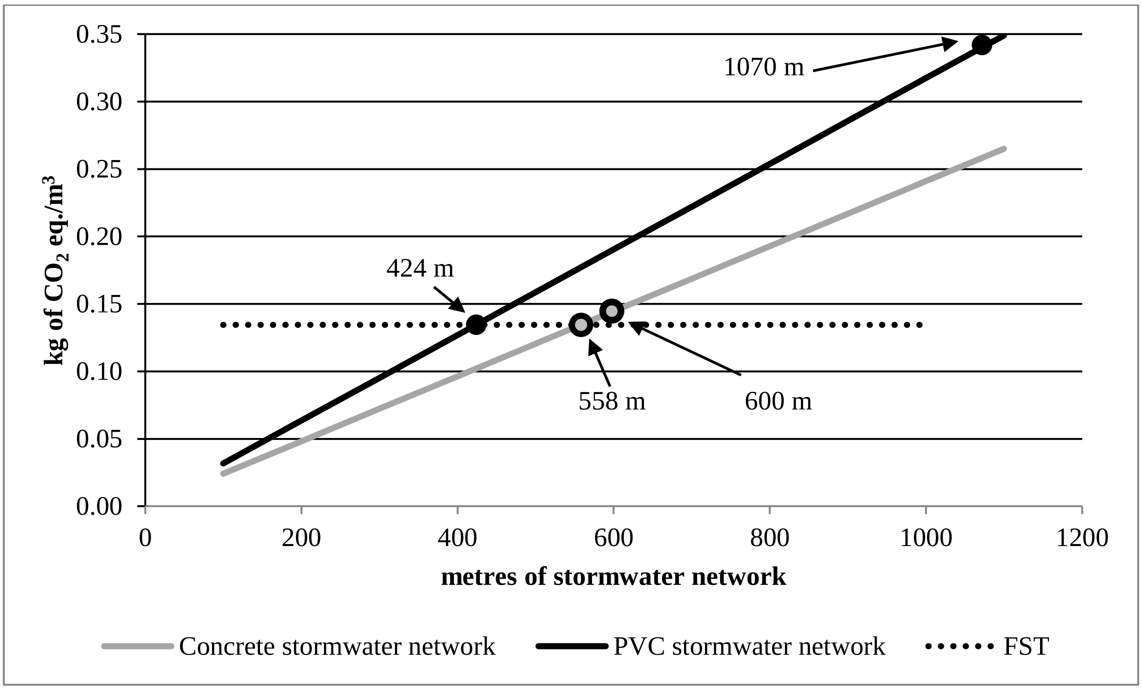

Figure 5 Comparison of the CO_2eq./m^3 of concrete and PVC stormwater pipes with a diameter of 300 mm and variation depending on the pipe length

4.3 Sensitivity analysis

The lifespan of the infrastructure is a critical issue when assessing its environmental and economic costs. The lifespan depends on different external factors, such as the stormwater quality, the rainfall intensity and the management practices. Considering these aspects and the structural configuration of each component of the FST, 4 lifespan scenarios were composed (**Supplementary Material 4**):

- Baseline: All of the components have the same average lifespan (10 years).
- Sc 1: The channel, which consists of concrete and steel parts, is not significantly affected by the management of the FST and has a longer lifespan. In contrast, the remaining components experience a rapid degradation due to erosion and thick sediment deposition that hinders infiltration.
- Sc 2: The geo-textile needs to be replaced every 5 years because it is easily blocked by sediments.
- Sc 3: The grass cover, which is mainly responsible for the natural infiltration, is eroded or compacted due to a lack of proper management practices.
- Sc 4: The channel collapses because of an accumulation of stormwater and the occurrence of intense and sudden precipitation.

As a result, variations in the total environmental and economic impacts of the FST exist, considering a time span of 100 years of analysis (**Figure 6**). There is a 40-50% increase in Sc 1 with respect to the baseline scenario, highlighting the effect of shortening the lifespan of various components of the system, some of them with an important contribution to the select indicators (**Figure 3**). In addition, in Sc 3 there is an important increase in the CED (40%). In this case, only the grass cover needs to be replaced more frequently. However, this component accounts for almost 70% of the CED and is responsible for the changes in this indicator. There is one scenario that does not differ much from the baseline. In Sc 4, only the channel needs to be replaced, but given that its contribution to the select indicators is not high, the results increase by 7-18%. Therefore, the individual management of each component is crucial in the durability and environmental performance of the entire system.

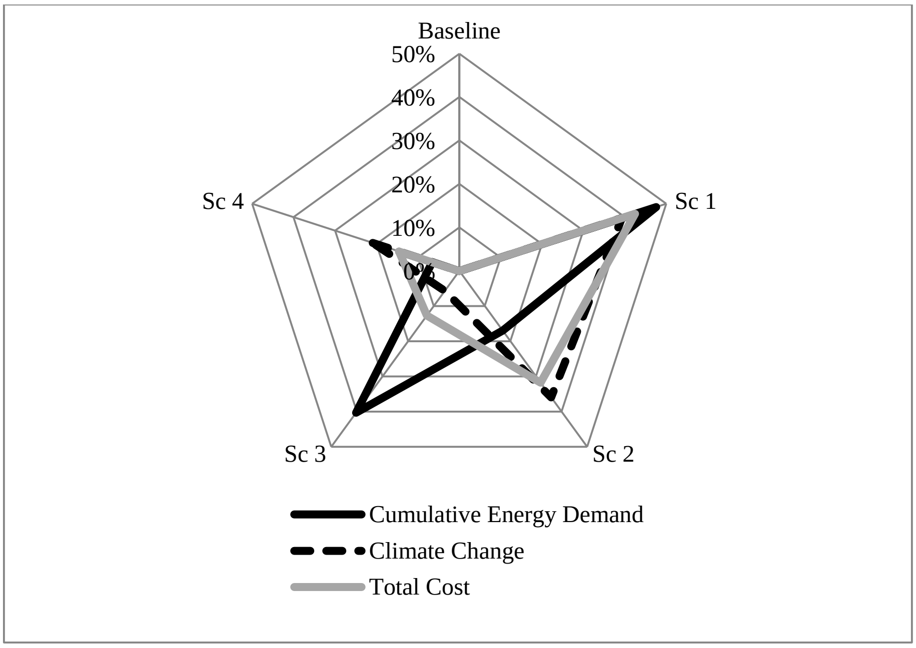

Figure 6 Sensitivity analysis of the Cumulative Energy Demand, Climate Change and Total Cost with different lifespan scenarios

5. Conclusions

Stormwater management is of paramount importance for preventing flooding events in wet areas and regions with intense and sudden rainfall events. This study assessed the environmental and economic impacts of a stormwater BMP that was implemented in Brazil. Three main conclusions could be drawn from this analysis:

(1) The FST significantly contributes to a reduction in the stormwater runoff (80-95%) in the area under study. In terms of impact, the life cycle of the FST entails 0.13 kg CO_2eq./m^3 and 0.35 USD/m^3. The LCA and LCC provide a first estimation of the implications of investing in this type of system and which are the aspects that could have a greater improvement potential.

(2) Considering the transport of an equivalent volume of that infiltrated by the FST, the latter is presented as a feasible source-control option when the pipeline needs to connect with a discharge point located far away from the catchment area. In addition, an integrated assessment of the ecosystem services of the FST would shed light on further benefits and drawbacks of this system.

(3) The management of the FST is crucial to increasing its lifespan and reducing the environmental impacts of the system. Therefore, the system needs to be assessed under different stress conditions to propose the best designs in different scenarios.

Given that this paper presented the life cycle impacts of an FST, future studies should focus on determining the net environmental and economic impacts resulting from its implementation as a flood prevention technique. In other words: when an FST is implemented, floods might be prevented or mitigated and the consequent material and economic losses of these events (i.e., cars, buildings, roads, etc.) might also be prevented. Hence, there should be a net balance between the investment and the benefits of using this type of system. Additionally, these results should be compared with the impacts and benefits of implementing other types of BMPs.

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