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Brudler, Sarah; Arnbjerg-Nielsen, Karsten; Rygaard, Martin

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# Accounting for multiple functions in environmental life cycle assessment of storm water management solutions

Solutions pour la gestion des eaux pluviales : mise en perspective de différentes approches par Analyse de Cycle de Vie

S. Brudler<sup>1,2</sup>, K. Arnbjerg-Nielsen<sup>1</sup>, M. Rygaard<sup>1</sup>

1 Technical University of Denmark, Department of Environmental Engineering

2 VCS Denmark

## RÉSUMÉ

Planifier l'adaptation au changement climatique en milieu urbain implique de plus en plus la mise en œuvre de différentes mesures de gestion locale pour la rétention et le traitement des eaux pluviales. L'ajout d'éléments « verts » ou « bleus » versatiles et à fonctions multiples modifie les environnements urbains et leurs usages, loin des approches de drainage souterrain classiques. Ces nouveaux éléments requièrent également la mise en pratique de nouveaux processus de gestion et de maintenance. La modification des impacts environnementaux par ces nouveaux types de gestion des eaux pluviales peut être quantifiée par des méthodes d'analyse de cycle de vie. Cette étude propose de définir les différentes fonctions fournies par un système de gestion des eaux pluviales, puis de les analyser du point de vue de leurs impacts environnementaux. L'approche est testée sur le quartier de Nørrebro, Copenhague, Danemark. Ce quartier fait l'objet d'une implémentation intensive de structures « vertes » dans le but d'atténuer les impacts du changement climatique. Ce scénario « vert » est ensuite comparé à un scénario classique « gris », impliquant uniquement le réseau souterrain. Les impacts environnementaux, dominés principalement par la production de matières dans les deux cas, sont nettement inférieurs dans le cas du scénario « vert » (35% de réduction contre seulement 8% pour le scénario « gris »). L'allocation des impacts démontre que les différentes fonctions d'un système de gestion des eaux pluviales peuvent avoir des impacts nettement différents.

## ABSTRACT

The wide range of approaches to handle storm water runoff have varying effects on the environment. Local stormwater control measures for retention and treatment are increasingly used components in urban climate adaptation plans. Often, these solutions modify the multiple functions of urban environments by adding green and blue elements, and they change the water balance compared to traditional, underground approaches. Additionally, different implementation and maintenance processes are required. All of these transformations affect the environmental impacts of urban storm water management (SWM) systems, which can be quantified using Life Cycle Assessment (LCA). This study aims to define the multiple functions provided by a SWM system at sub-catchment scale, and to assess the environmental impacts arising from fulfilling these functions. The approach is tested using the Nørrebro catchment in Copenhagen, Denmark, where extensive implementation of green infrastructure is planned to mitigate the adverse effects of climate change. This « green » scenario is compared to a traditional « grey » solution, utilizing pipes and basins. The environmental impacts, which are dominated by material production in both scenarios, are significantly lower for the « green » solution (35% down to 8% of the “grey” impacts). The allocation of impacts shows that the various functions of the SWM systems cause different impacts.

## KEYWORDS

Life Cycle Assessment; stormwater management; functional unit; Three Points Approach

## 1 INTRODUCTION

Life Cycle Assessment (LCA) is an internationally standardized method to quantify the environmental impacts of products, services and systems from material generation to disposal (European Commission, 2011). It is chosen in this study to assess the environmental impacts of two storm water management (SWM) systems. Water technology choices and management are increasingly supported by LCA. However, urban water systems are very complex and consist of numerous different elements fulfilling different functions. This complexity demands collection of large amounts of data. Additionally, the different functions of the single elements and the necessary interaction to provide a functioning water system complicate the assessment. Previous studies often focus on single elements, e.g. green roofs (Chenani et al., 2015), or a selected function of stormwater infrastructure, e.g. the detention and treatment of a specific water volume (Vineyard et al., 2015). Only few researchers look into entire SWM systems such as reduction of sewer overflows and pluvial flooding. Such systems consisting of multiple elements are necessary to solve flooding problems and meet water quality requirements. Only by assessing a complete SWM system, the environmental impacts of fulfilling these two main functions can be quantified. This approach also allows inclusion of additional functions not directly linked to SWM, e.g. recreational benefits.

A crucial step in LCA is the definition of the functional unit, as all inputs and outputs are directly related to it. It describes the elementary function that the assessed product, service or system has to fulfil. In previous research in LCA of SWM systems, a wide range of definitions has been used ranging from specific drainage areas, to the treatment of a runoff from a specific area, to a certain water volume, or the treatment of that volume. No consistent approach has been established and all approaches partly neglect functions of SWM elements. In a novel approach, we use a terrestrial LCA as introduced by Loiseau et al. (2013). The method is adapted to evaluate two scenarios for handling storm water in the City of Copenhagen, Denmark. Both incorporate pipes, and the “green” scenario additionally introduces elements to locally retain and treat runoff, while the “grey” scenario completely manages runoff underground in pipes and basins. The objective is to define the different functions directly related to SWM and to calculate the environmental impacts that are caused by fulfilling them.

## 2 MATERIAL AND METHODS

Instead of defining one single functional unit, a reference flow is specified as the catchment area of 2.6km<sup>2</sup> (Loiseau et al., 2013). From this, different functions can be derived, which are identical for all scenarios. These functions are based on the Three Points Approach (3PA), which divides rainfall events in domains according to their frequency (Fratini et al., 2012; Sørup et al., 2012): Domain A includes all rain events up to a return period of 0.2 years, while domain B events have a maximum return period of 10 years and domain C events of 100 years. The water balance and the flow paths through the different elements of the system are analysed for the different domains.

Both scenarios are assessed over a period of 100 years, which equals the planning horizon of the SWM plan. This induces operation and renewal demands that vary between the different elements. These demands are characterized by a high uncertainty, as they are very dependent on local conditions, and only limited data is available as “green” SWM is still quite new. Data from planning documents, literature and databases is compiled and used as inputs to the process model created using EASETECH (Clavreul et al., 2014). The impacts in 14 midpoint categories are calculated using the ILCD recommended method (European Commission, 2011). The results are normalized with reference to the average impact per person per year.

## 3 RESULTS AND CONCLUSION

For the three different rain domains, different safety levels are defined as the functions that have to be fulfilled by the system. Different strategies to achieve these functions are applied in the two scenarios (Table 1). The flow path of water through the system varies for the different domains, which is visualized exemplarily for the “grey” system in Figure 1.

Table 1: Functions derived from the reference flow of the LCA, and strategies of both scenarios

Function	Strategy “green” scenario	Strategy “grey” scenario
Function 1: Manage 30% of present and 100% of additionally expected runoff with a return period (T) = 0.2 years (domain A)	Local retention and infiltration in green elements	Extension of the existing underground sewer system and treatment at an existing wastewater treatment plant
Function 2: Ensure no water on the surface for events with T = 10 years (domain B)	Discharging water in channels above the surface to local retention volumes / Sortedams Sø	Storing water in retention basins
Function 3: Ensure max. 10cm of water on the surface for events with T = 100 years (domain C)	Discharging water in channels above the surface to local retention volumes / Sortedams Sø	Overflow to the harbor

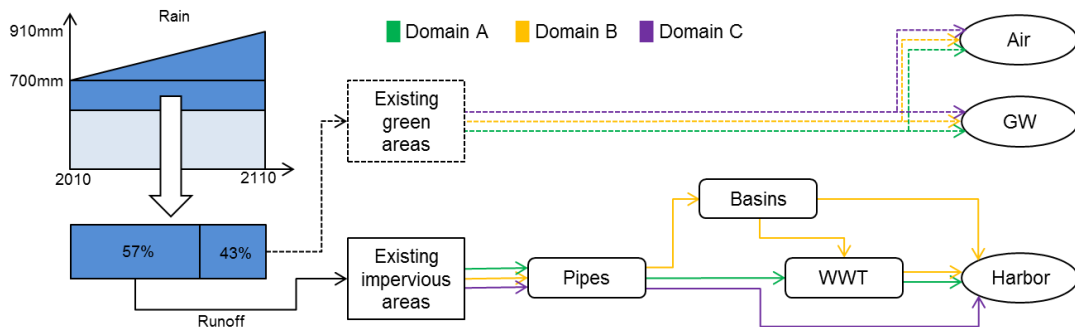


Figure 1: Simplified water balance showing the path from rain to runoff through the system, for the “grey” scenario

The impacts of implementing, operating and decommissioning are analysed for both systems. Eight out of 14 midpoint impact categories are identified as particularly relevant for the evaluation. The “green” scenario has lower impacts in all of them (41% down to 13% of the “grey” impacts), ranging from 5 to 30 person equivalents (PE)/2.6km<sup>2</sup> per year. The results from the “grey” scenario vary between 14 and 122 PE/2.6km<sup>2</sup>.year (Figure 2). In both scenarios, the main impacts result from material generation. Transport of material to the construction site is the second most important life cycle stage in the “green” scenario, while the operation phase contributes significantly through the wastewater treatment (WWT) in the “grey” scenario. Electricity consumption at the wastewater treatment plant is based on the current Danish power generation mix, which is dominated by fossil fuels. As the Danish government is planning to shift towards more sustainable energy sources and the temporal scope of the assessment is 100 years, the resulting impacts from electricity use are possibly less significant. Another source of uncertainty are the system designs. In the “grey” scenario, the number of basins could be reduced, which subsequently reduces the material demands. Similarly could channels in the “green” scenario be changed from rectangular concrete structures to more green solutions, such as trenches parallel to the road.

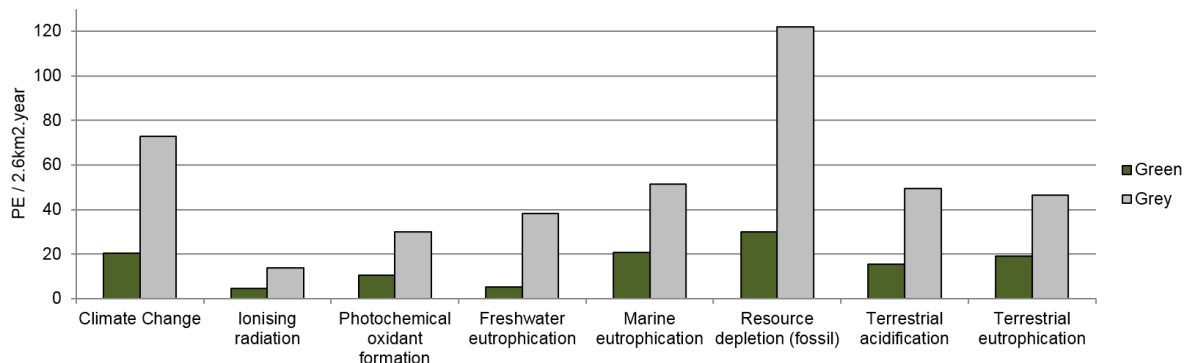


Figure 2: Normalized impacts per year of the two scenarios, for eight selected midpoint categories

Exemplarily for the “grey” scenario, the impacts of the single scenarios are allocated to the different functions based on the water balance. Handling extreme events up to a return period of 10 years (domain B) causes the main share of impacts (29% to 81%). Management of everyday events (domain

A) also leads to significant impacts (2% to 46%), while extremely rare events (domain C) account for less than 1% in all impact categories. Some of the impacts cannot be allocated because they do not arise when fulfilling a SWM function. This share can be quite high (up to 65%) and arises mainly from renewal of roads in the “grey” system, which does not contribute to SWM.

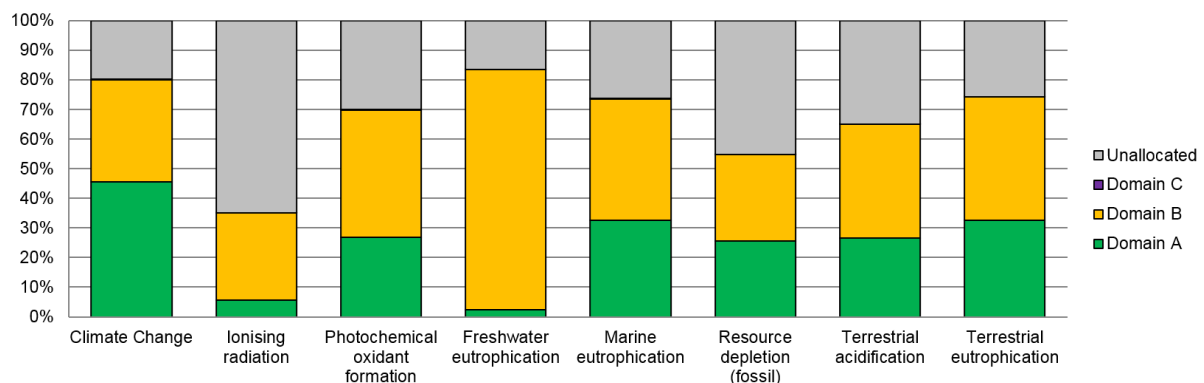


Figure 2: Normalized impacts per year of the two scenarios, for eight selected midpoint categories, allocated to the different functions related to SWM (domain A, B, C), and not directly related to SWM (unallocated)

The terrestrial LCA approach proves to be suitable to assess SWM solutions, as it allows incorporating different functions of complex systems. The analysis of the complete sub-catchment confirms that it is essential to include all elements, as especially for the “green” system, they all contribute significantly to the environmental impacts. Only by combining these elements can the different flood safety levels, defined as functions, be reached. The allocation of results to the functions shows that handling of rain events up to a return period of 10 years causes the greatest impacts in the “grey” system. It also indicates that the impacts are partly caused by functions, which have no direct relevance for SWM.

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