Environmental Assessment of Sewer Infrastructures in Small to Medium Sized Cities Using Life Cycle Assessment

MSc Anna Petit Boix

MSc David Sanjuan
Dr Carles M. Gasol
Dr Gara Villalba
Dr María Eugenia Suárez

Dr Joan Rieradevall
Dr Alejandro Josa
Dr Xavier Gabarrell

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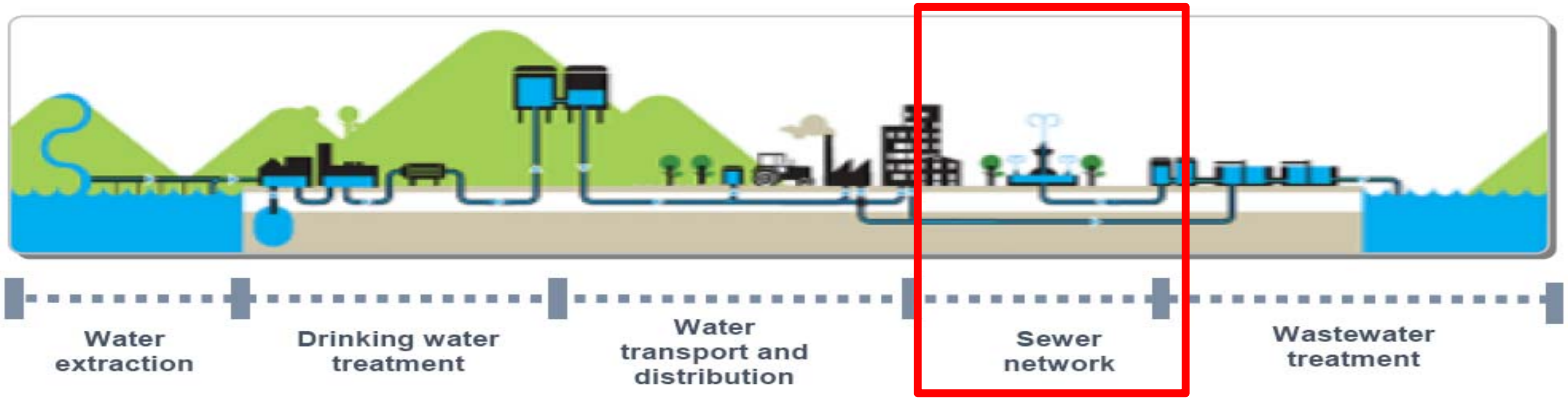
Context

In the framework of the LIFE Aquaenvec project → Assessment of the entire urban water cycle



Environmental impacts of the pipe production, installation and demolition of the sewer infrastructure

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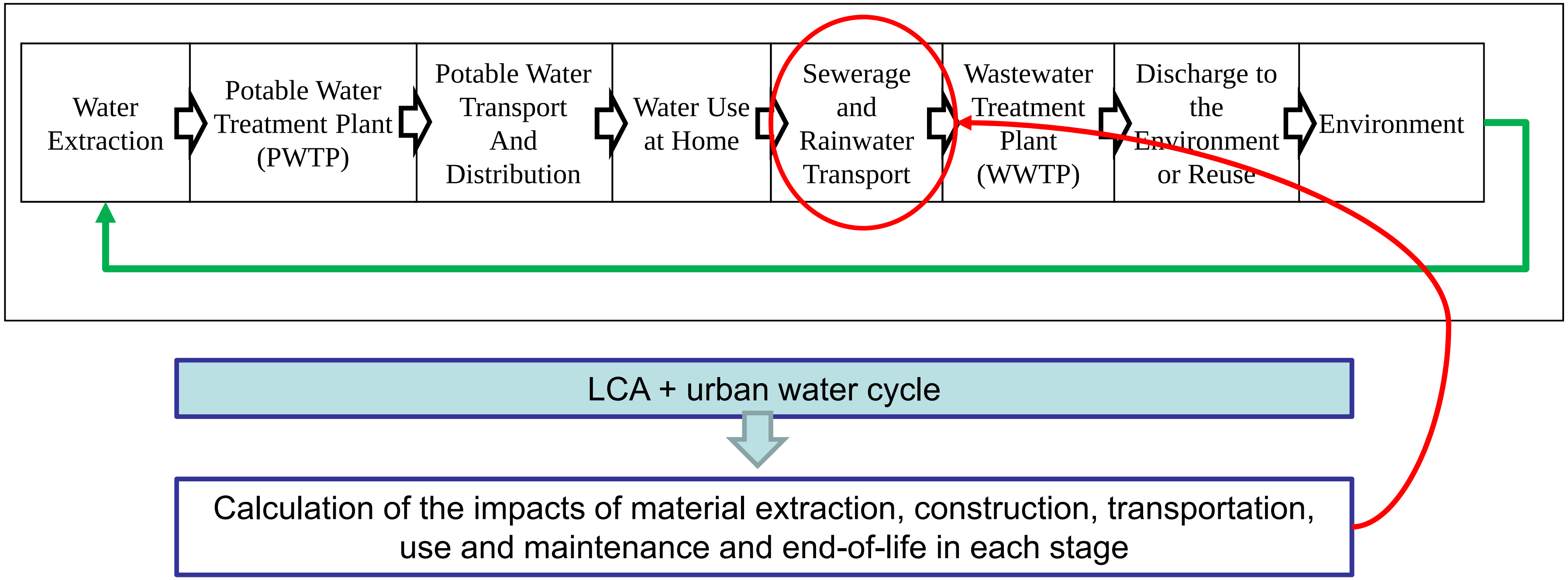
1. Introduction. The urban water cycle and LCA

The management of the urban water cycle in cities must be considered to:

- meet the sanitary requirements of an ever-growing population
- provide good water quality 'status'
- tackle sustainability



1. Introduction. The urban water cycle and LCA

MAIN IMPACTS		
	Water discharge	Lassaux et al. (2013)
	Electricity use for water heating	Klein et al. (2005); Arpke and Hutzler (2006); The Environment Agency (2008); Griffiths-Sattenspiel and Wilson (2009)

Wastewater system

WWTPs have been studied in many cases

PROBLEM: Studies with component aggregation (sewer + WWTP)

Contributions are difficult to identify

1. Introduction. The urban water cycle and LCA

Use phase depends on:
- Length of the system
- Topography
- Location of the urban elements

The sewer system:

Globally:	Sewer system scores worse than WWTP in 10 of 15 impact categories	Roux et al. (2011)
Stages:	Main contributors: Construction materials and civil works	Roux et al. (2011)
Civil works:	• Aspects to consider: material removal, excavation and use of energy	Anders and Anders (1997) Nielsen et al. (1998)
	• When the sewer system stops growing: GHG (operation, maintenance and rehabilitation) = 3 x GHG (production and installation)	Venkatesh et al. (2009)
Construction materials:	83% of the GHG of a pipeline life-cycle are related to the construction and embodied emissions of the materials used to manufacture it	Strutt, et al. (2008)

1. Introduction. The urban water cycle and LCA

The sewer system:

Concrete:	**Scores always better than PVC and vitrified clay:** • Petroleum is used to produce PVC • Concrete has 1.5-4.2 less emissions	INTRON (1995)
	Longer lifespan (more than 50 years) • Scores better in resource scarcity indicators	Anders and Anders (1997)
	In concrete pipes: •Greatest contributor to CO_2 emissions is the **cement production** (40%), followed by transport and landfill (30%)	Lundström et al. (1996); van Drunen et al. (2000)
Iron:	•10-15 higher environmental impacts than PVC, PE, HDPE and fibrocement	Geberit International AG (1998)
PVC and PE:	**The smallest pipelines:** • GHG are 10-26 times greater than concrete	Venkatesh et al. (2009); Viñolas (2011)

1. Introduction. The urban water cycle and LCA

Environmental burdens of the sewer system are not clear

→ Use stage is site-dependent

Studies mainly focus on pipes

→ Insufficient data on trench materials

Sewer appurtenances are generally excluded

→ The entire system must be analysed

CONSTRUCTIVE SOLUTIONS AND APPURTENANCES

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2. Goal and scope

2.1 Objectives

MAIN GOAL:
To quantify the environmental impacts of a sewer system and to determine the most environmentally friendly design strategy for small to medium sized cities

SPECIFIC OBJECTIVES:

- ❑ To develop an inventory of the material and energy inputs in the life cycle of a sewer system
- ❑ To identify the impacts of the production, transport, installation and demolition stages of standard constructive solutions by pipe material, section and trench design and sewer appurtenances using LCA
- ❑ To propose a methodology for the estimation of the network's global impact based on the aggregation of the individual elements (constructive solutions and appurtenances) and to facilitate the decision-making process
- ❑ To check preliminarily the methodology of the infrastructure of a small city
- ❑ To analyse and discuss possible eco-efficiency indicators (impact per capita, per m^2 or m^3) to propose the best constructive solutions

2. Goal and scope

2.2 Declared units and Functional Unit

Declared units (DU)

Constructive solutions

1 linear metre of pipe with

Diameters	Materials
Ø 110 mm Ø 300 mm Ø 800 mm Ø 1200 mm	Concrete Fibrocement PVC HDPE

over 100 years

In a specific city

Sewer appurtenances

1 unit of sewer appurtenance

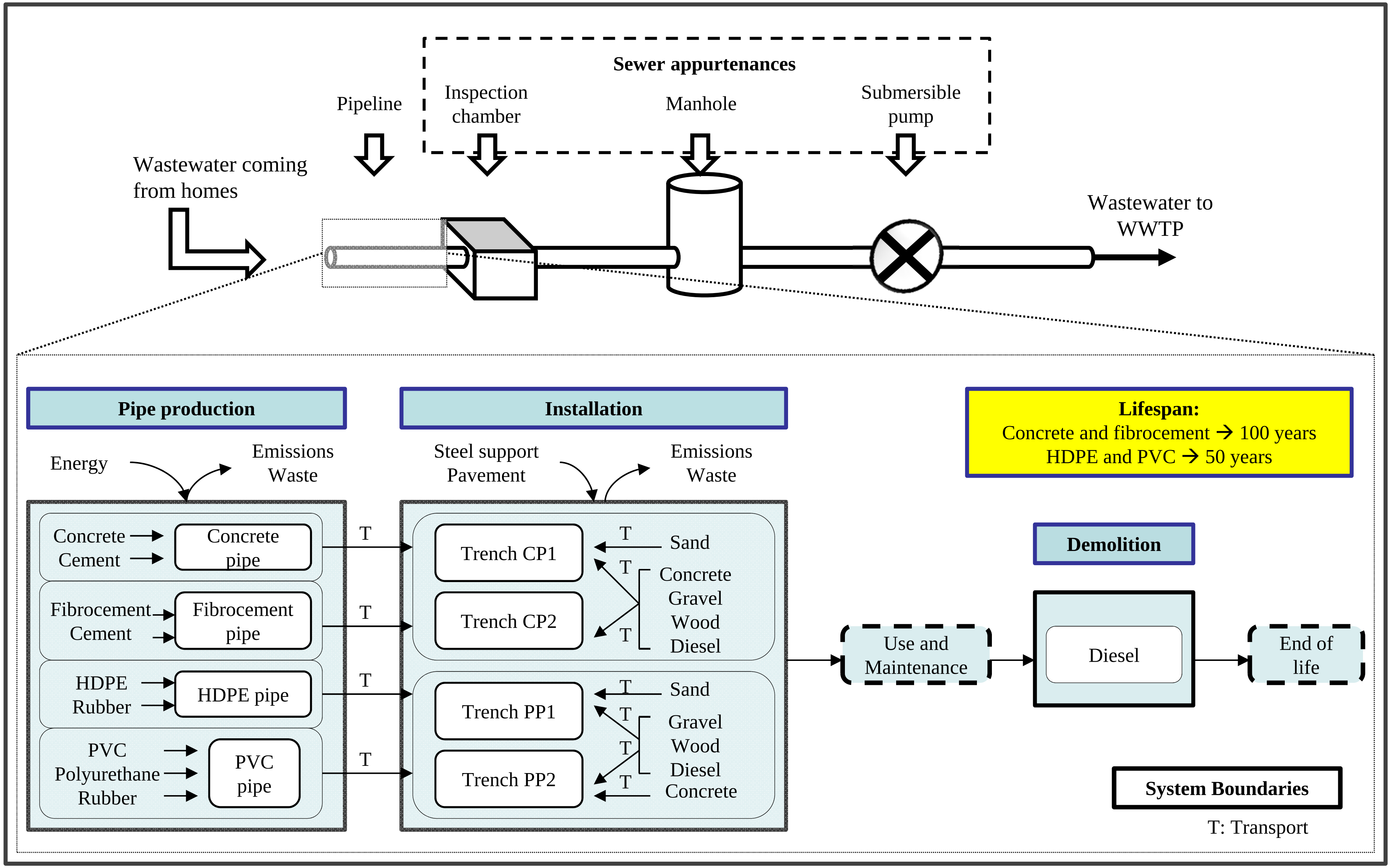
Manhole *(1 unit every 50 m)*
Inspection chamber
(1 unit every 50 m)
Pump

over 100 years

Functional Unit (FU)

The infrastructure necessary for the collection and transportation of 1 m^3 of wastewater in small to medium sized cities in a year

3. Materials and Methods

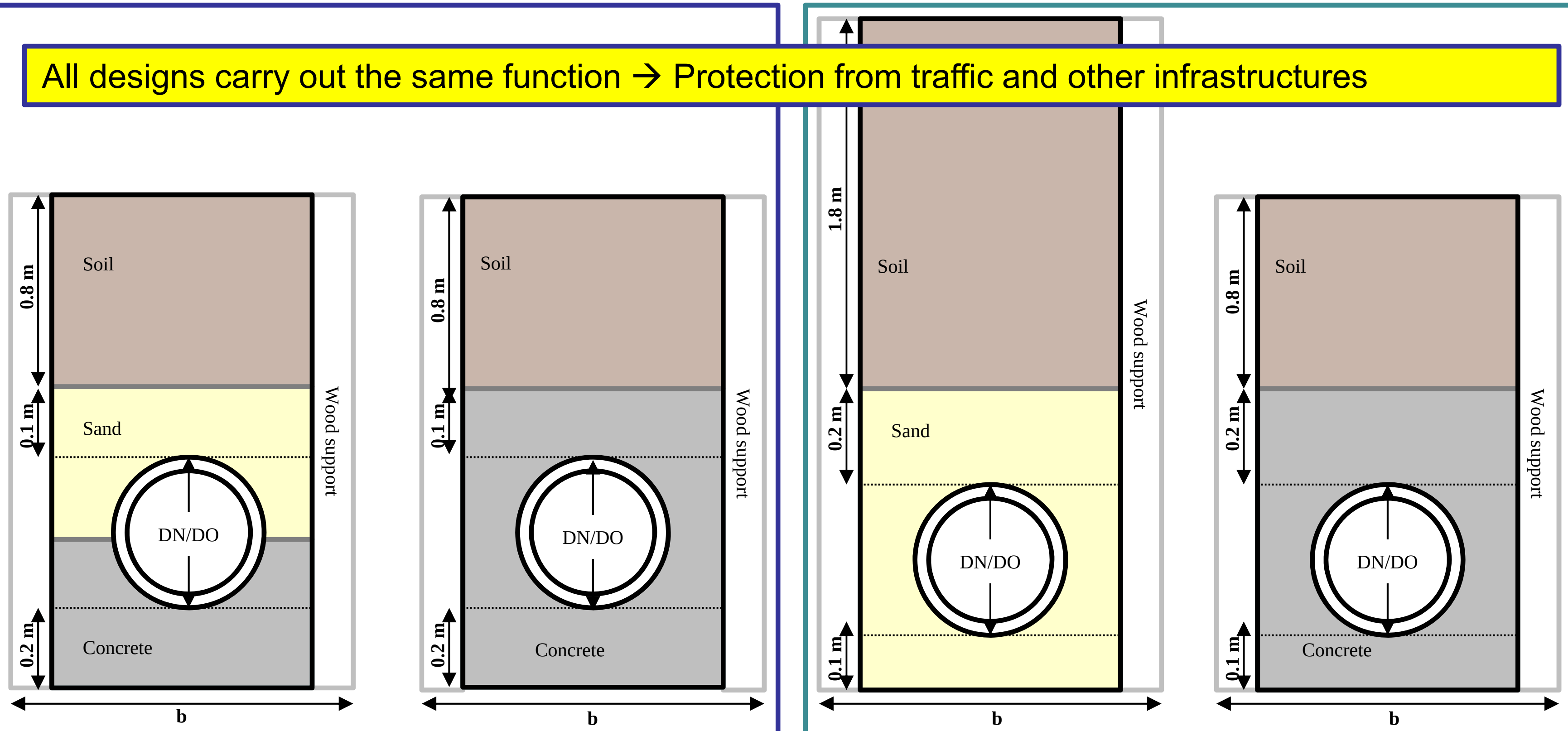


3. Materials and Methods

Installation stage: trench designs (adapted)

Concrete and fibrocement pipes	HDPE and PVC pipes

All designs carry out the same function → Protection from traffic and other infrastructures



CP1 CP2 PP1 PP2

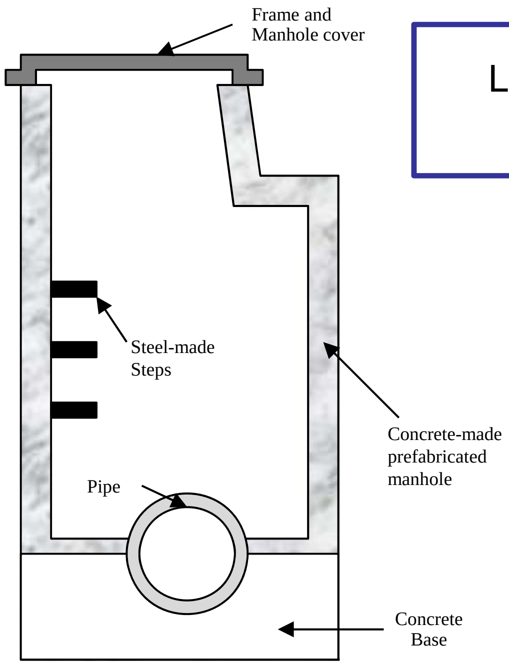
3. Materials and Methods

Sewer appurtenances

Submersible pump

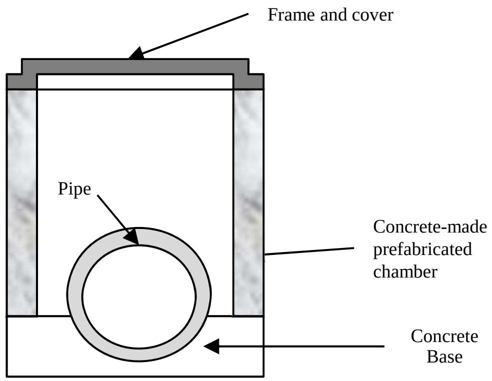
Assumptions:
60 m^3/h
At the bottom of a manhole
Lifespan: 10 years

Manhole



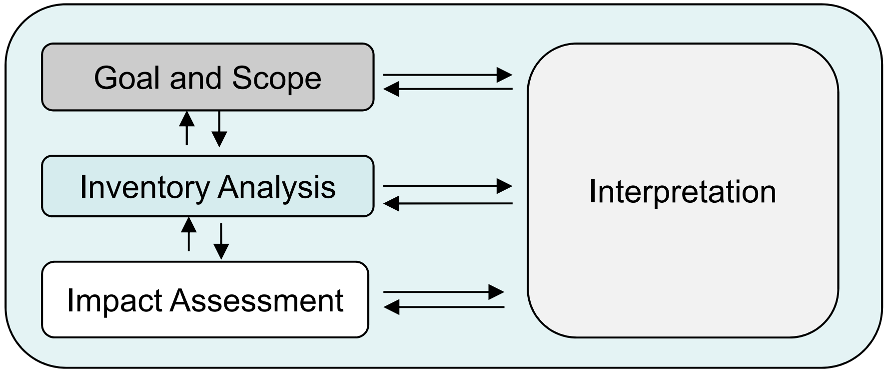
Lifespan: 50 years
1 every 50 m

Inspection chamber

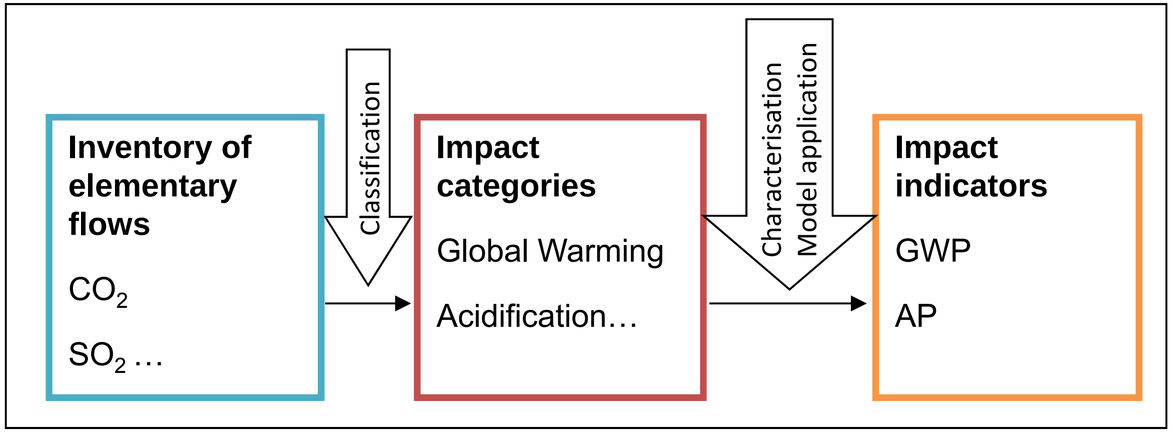


3. Materials and Methods

Methodology: Life Cycle Assessment (LCA)



ISO Standard 14040



3. Materials and Methods

Methodology: Life Cycle Assessment (LCA)

LCA Tools:

Methods: CML 2 baseline 2000 V2.05 Cumulative Energy Demand V1.08
Database: Ecoinvent 2.2
Software: SimaPro 7.2.0

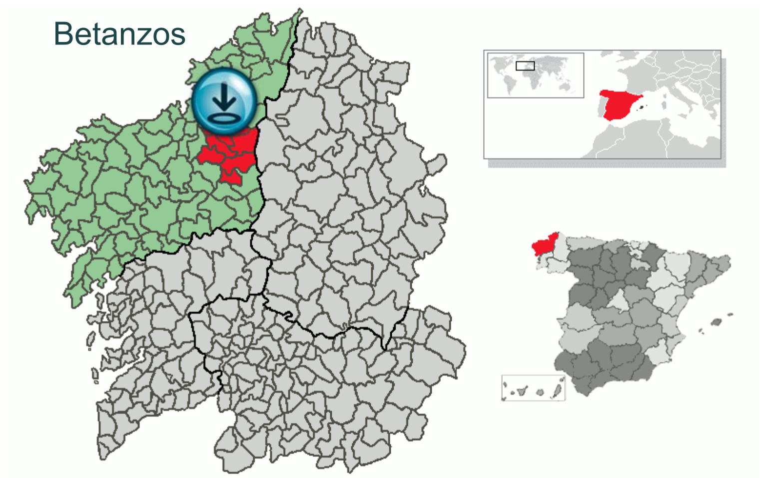
Data sources:

Standard sewer designs:
CLABSA (Clavegueram de Barcelona)
MetaBase ITeC (http://www.itec.cat/nouBedec.c/bedec.aspx)
Centre for Hydrographic Studies (CEDEX, 2009)

Case study:
Private databases CONTEC© & GISAgua©

3. Materials and Methods

Case study: Betanzos (Galicia, Spain)



Population: 13,537 inhabitants (2011)

Area: 24.2 km^2

Wastewater production: 95,475 m^3/year (2011)

Climate: Atlantic

Precipitation: above 1,000 mm/year

↑ pipe requirements

↓ Structural complexity

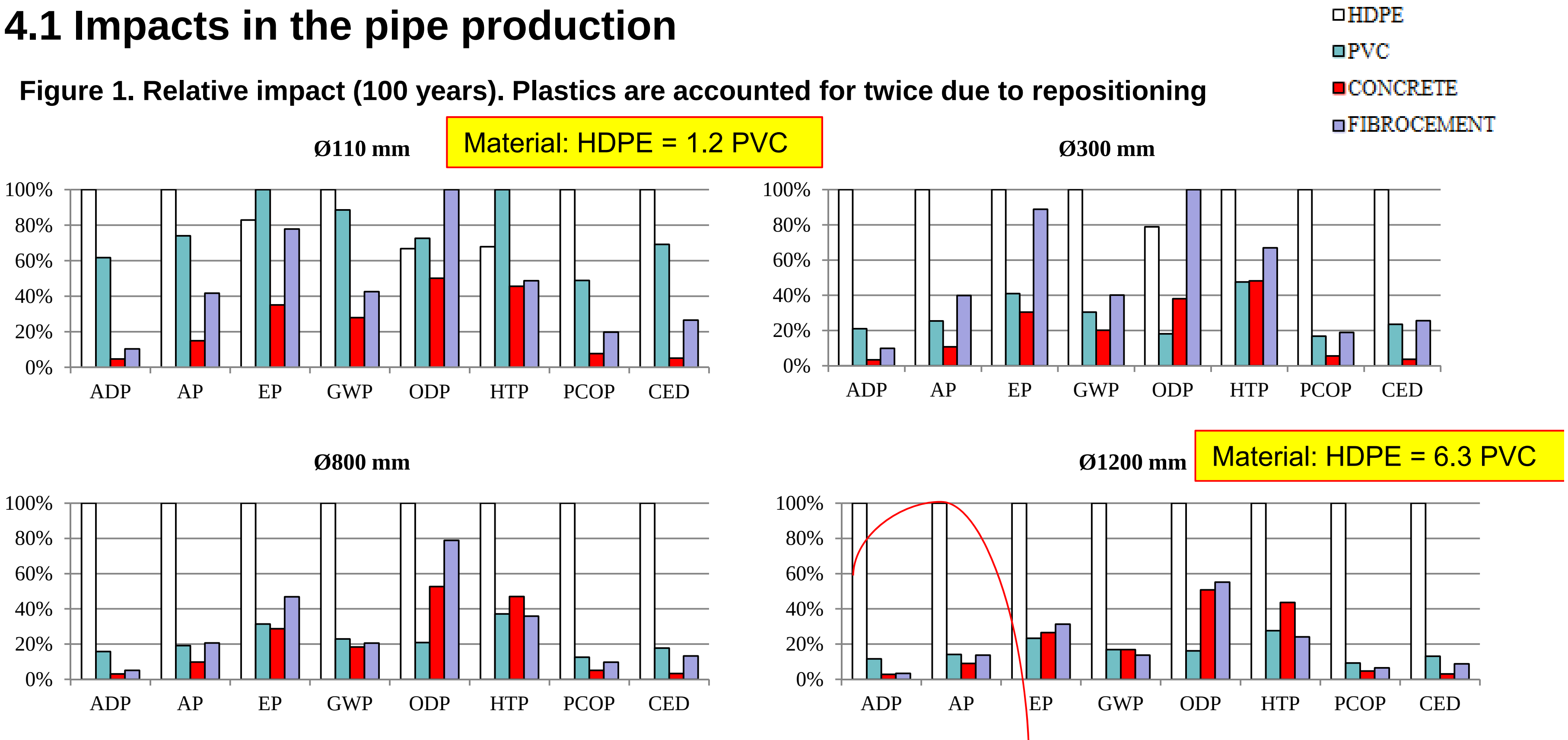
Table 1. Materials and diameters in Betanzos

Diameter intervals (mm)	Length (km)	Materials			
		PVC	HDPE	concrete	fibrocement
[63-110]	3.2	57%	43%	0%	0%
(110-250]	14.2	89%	3%	5%	2%
(250-400]	60.5	61%	0%	36%	3%
(400-1200]	1.3	0%	0%	100%	0%
Total	**79.2**				

4. Results and Discussion

4.1 Impacts in the pipe production

Figure 1. Relative impact (100 years). Plastics are accounted for twice due to repositioning



HDPE is up to 30 times higher

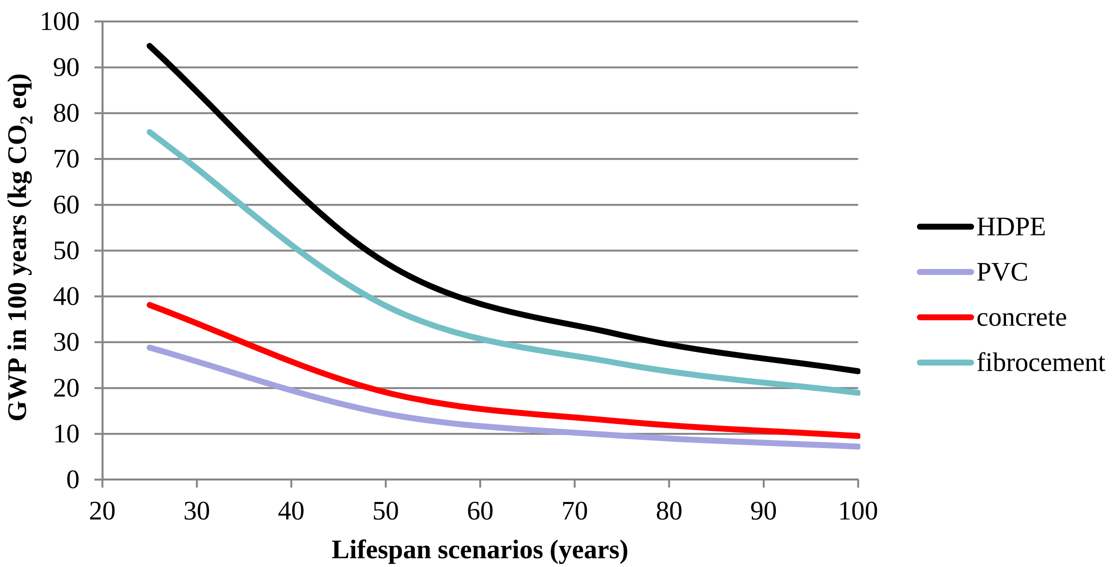
Plastics → 90% oil derivatives
Concrete and fibrocement → 40-75% cement contribution

HDPE: material requirements increase faster with Ø

4. Results and Discussion

4.1 Impacts in the pipe production

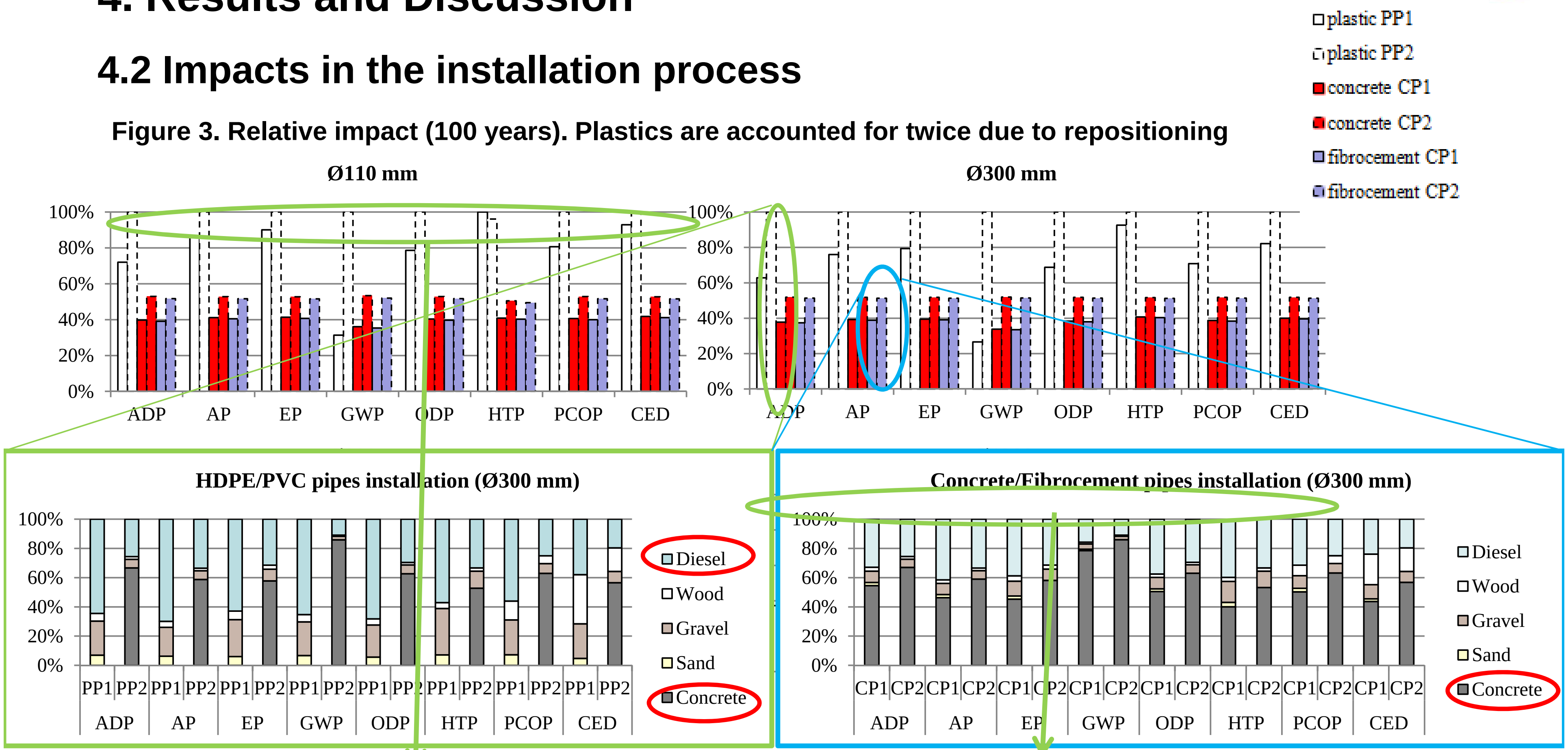
Figure 2. Sensitivity analysis considering different lifespan in a 100 period



4. Results and Discussion

4.2 Impacts in the installation process

Figure 3. Relative impact (100 years). Plastics are accounted for twice due to repositioning



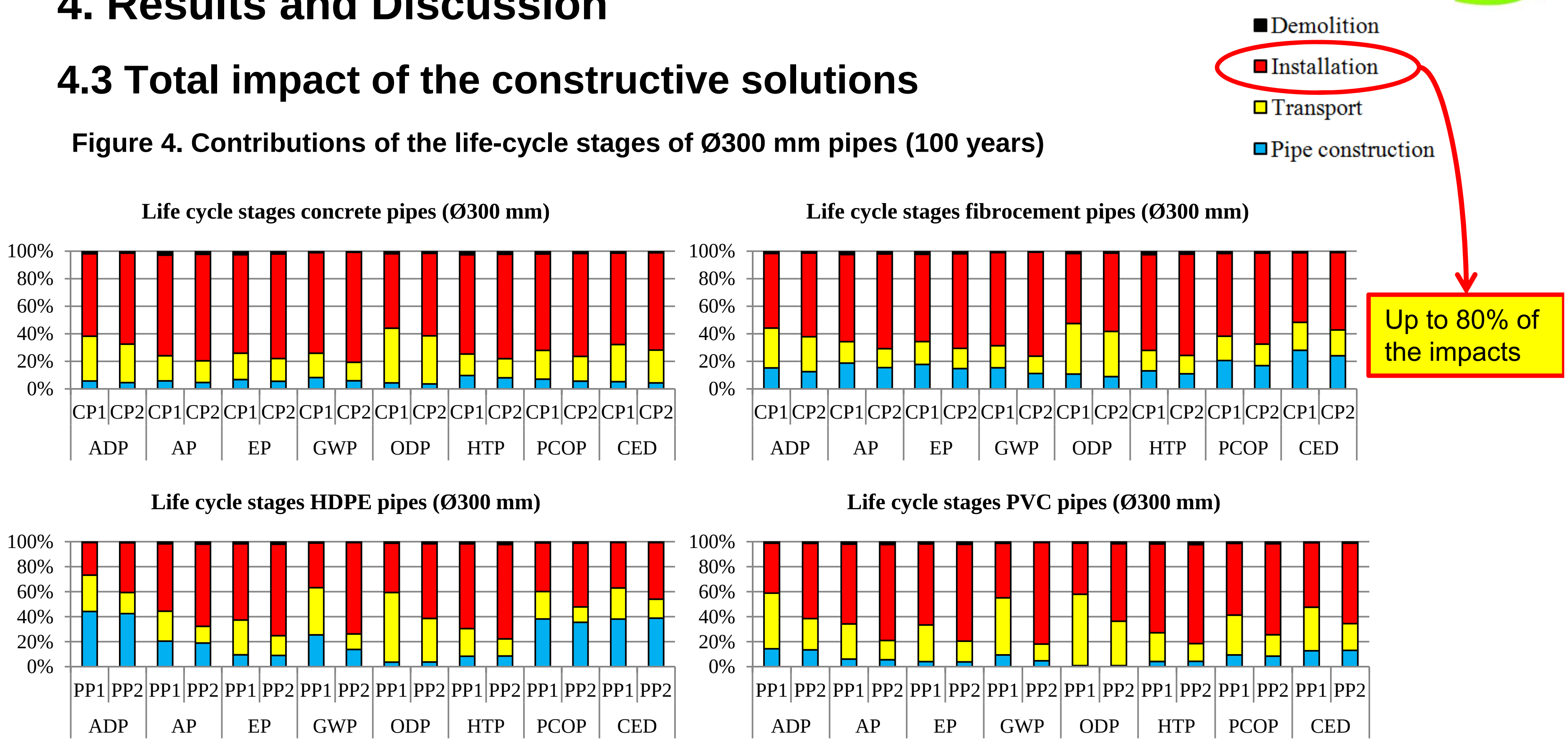
Diesel is more relevant than concrete

Concrete is more relevant than diesel

4. Results and Discussion

4.3 Total impact of the constructive solutions

Figure 4. Contributions of the life-cycle stages of Ø300 mm pipes (100 years)



Best design: Concrete and fibrocement with trench design CP1 (20-30% of the impact of HDPE)

Worst design: HDPE pipes with trench design PP2

4. Results and Discussion

4.4 Impact of the sewer infrastructure (pipes+appurtenances)

1 m of pipe

Ø300 mm PVC+ PP2

→ 2% of a manhole → 1 every 50 m

→ 2% of an inspection chamber → 1 every 50 m

→ ? pump (depends on the city requirements)

In terms of impact:

Table 2. Relative impacts in terms of 1 metre of pipe

Impact category	Pipe	Manhole	Inspection panel
ADP	79%	18%	3%
AP	79%	17%	4%
EP	64%	30%	6%
GWP	84%	14%	2%
ODP	85%	13%	2%
HTP	48%	43%	9%
PCOP	67%	28%	5%
CED	82%	15%	3%

Manholes should not be underestimated

4. Results and Discussion

4.5 Betanzos: Impact of the sewer infrastructure

Table 3. Pipes selected in the study

Diameter (mm)	Length (km)	Materials: PVC	HDPE	concrete	fibrocement
110	0.8	7%	93%	0%	0%
300	57.3	61%	0%	39%	0%
800	0	0%	0%	0%	0%
1200	0.8	0%	0%	100%	0%
Total	**58.9**				

1600 manholes, 1600 inspection chambers and 13 pumps

Eco-efficiency indicators. Cannot be compared yet.

Table 4. Impacts in Betanzos

50% reduction

	Total impact (100 years)		Impact per capita/year		Impact per m^2/year		Impact per m^3/year	
	ST1	**CP1**	**ST1**	**CP1**	**ST1**	**CP1**	**ST1**	**CP1**
GWP (kg CO_2eq)	1.3E+07	2.0E+07	9.9E+00	1.5E+01	5.5E-03	8.4E-03	1.4E+00	2.1E+00
CED (in kWh)	5.9E+07	6.0E+07	4.3E+01	4.4E+01	2.4E-02	2.5E-02	6.2E+00	6.3E+00

The impacts can be reduced by 10% by using ST1 in 4 of 8 mid-points

Appurtenances account for 22-64% of the impact

Improvement scenario: substitution of the 61% of PVC pipes for concrete pipes

30-40% impact reduction due to longer lifespan

5. Conclusions

Pipe Materials

Plastics (HDPE) present greater impacts than other materials (up to 30 times) due to:

- The material composition
- The shorter lifespan → Repositioning is required over 100 years

Concrete has the lowest impact

Installation

This stage was found significant → up to 80% of the total impact (except in big HDPE-made pipes)

Trench designs present different environmental burdens.

- The contribution of concrete beddings is important in big pipes
- The contribution of diesel becomes more relevant in small pipes

Total impact

Optimal infrastructure: concrete (and fibrocement) pipe with half-concrete/half-sand bedding (CP1)
Worst infrastructure: HDPE pipe with concrete bedding (PP2)

Technical requirements must be analysed more thoroughly

Demolition can be neglected, but transport accounts for 10-50% of the impact.

5. Conclusions

Methodology

The impacts of a medium/small city can be easily estimated by aggregating the DUs.

Case study in a small city: Betanzos

The sewer profile of Betanzos could be adapted to the materials and diameters selected for small to medium cities. >70% of the network consists of Ø300mm PVC pipes.

Estimated impact: 2.1 kg CO_2eq/m^3; 6.3 kWh/m^3

Sewer appurtenances account for 22-64% of the impacts

The use of concrete allows for impact reductions (30-40%)

Eco-efficiency indicators

These indicators facilitate the impact estimation in different regions and over different time periods

Data can be combined with the results of future economic studies

USE AND MAINTENANCE (U&M)

6. Use and Maintenance Stage

ANALYSIS OF THE USE AND MAINTENANCE STAGE

Energy consumption

↓

Statistical Analysis (Sample: 68 Spanish Cities)

↓

Parameters:
- Inhabitants
- Population density
- Seasonality
- Coastal/Inland
- WWTP location
- Length of the sewer

Maintenance

↓

% of reposition
Diesel consumption

Direct GHG emissions

↓

Literature review
Summer sampling campaign
Data treatment

Electricity consumption

68 municipalities were selected. Results for the year 2011

Significantly different

Seasonality	n	mean kWh/inhabitant	standard deviation	maximum	minimum
Seasonal	18	11.04	18.27	65.51	0.31
Non-seasonal	29	4.86	7.09	27.65	0.01

Population peaks in the touristic season

Climate	n	mean kWh/inhabitant	standard deviation	maximum	minimum
Atlantic	8	21.10	19.54	65.51	4.12
Mediterranean	35	4.56	9.19	51.85	0.01
Subtropical	5	4.01	5.68	13.93	0.57

Probably more precipitations, more consumption

City location	n	mean kWh/inhabitant	standard deviation	maximum	minimum
Coastal	26	10.99	16.03	65.51	0.24
Inland	22	2.85	3.78	13.60	0.01

Orography: more pumping requirements in flat areas

Population density (inhabitant/km²)	n	mean kWh/inhabitant	standard deviation	maximum	minimum
0-1,000	13	7.15	8.19	27.65	0.35
1,001-2,000	20	9.42	14.64	65.51	0.01
2,001-3,000	15	4.48	13.16	51.85	0.16

Low density derives in more sewer length/inhabitant → more aggressive maintenance

Electricity consumption

		Population	Total length of sewer	Total wastewater production	Total water flow	Water flow per capita
Total electricity consumption (kWh)	Pearson Correlation	0.632	0.790	0.597	0.333	0.380
	Sig. (2-tailed)	0	0	0	0.033	0.014
	N	48	47	48	41	41

Regressions between these parameters are currently being developed.

However, so far relationships were difficult to determine, as the electricity consumption in similar cities was very different.

7. Future actions

In-depth analysis of the use and maintenance stage

Measurement of direct Greenhouse Gas Emissions (CH_4, N_2O, H_2S)

Inclusion of more pipe materials and diameters

Determine the most suitable treatment solution in diffuse areas (e.g. septic tanks)

Analysis of other sewer elements such as rainwater retention tanks

Improvement of the mean of transport (e.g. diesel substitution)

Coupling with economic results (LCA+LCC)

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